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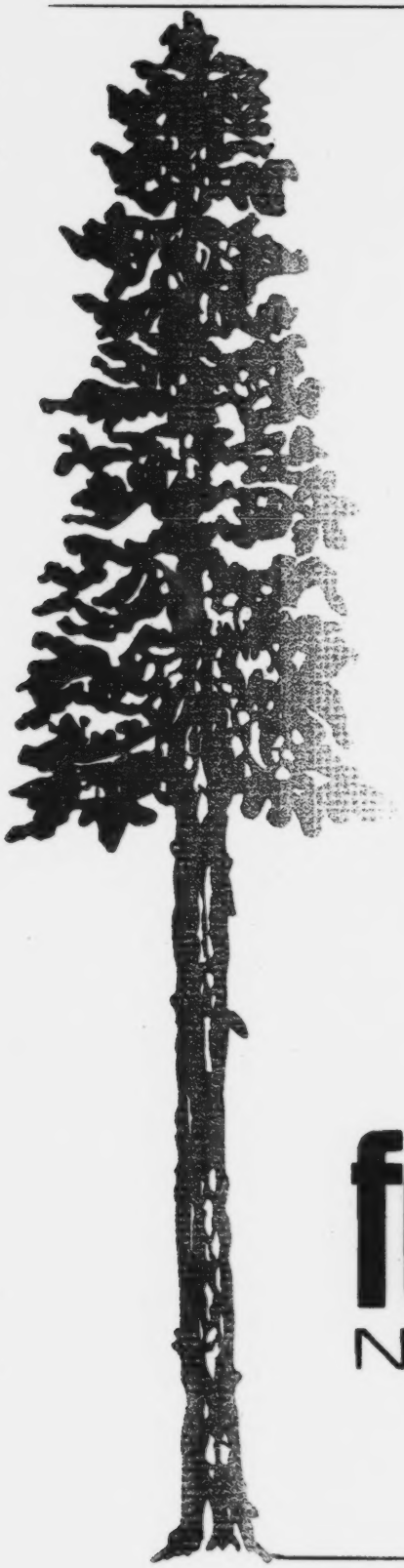

A Quantitative Evaluation of Natural Age Class Distributions and Stand Replacement Intervals in the Nelson Forest Region

Volume 1

J. Pollack, H. Quesnel, C. Hauk, and H. MacLean

Technical Report TR-015

forest sciences

NELSON FOREST REGION

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ABSTRACT

One of the cornerstones of the Biodiversity Guidebook (BGB) is the philosophy of protecting minimum proportions of specific forest age classes in the working forest. In the BGB, these minimum age class requirements are based on expert opinion, which consist of 1. an estimate of the average time between stand replacing events (SRI), and 2. an age class distribution generated from the SRI by a mathematical function - the negative exponential equation. The BGB notes that more precise determinations of natural age class distributions are the ideal basis for further refinements.

In practice, the BGB age class requirements are implemented using the operational forest inventory. Regional land use plans, landscape-level plans, and forest development plans must rely on this large data base. However, over the past eighteen months, experienced planners in the Nelson Forest Region expressed concern about the levels of old growth suggested in the BGB. An evaluation of six of the seven Timber Supply Areas in the Nelson Forest Region determined that only 20.3% of all landscape unit/variants can presently meet BGB old-growth requirements.

The current project was initiated to determine if the inventory could quantitatively validate the BGB values for the Nelson Forest Region. This study was conducted in two stages. In stage one, potential problems associated with the operational inventory were explored. The factors examined included different definitions of stand age, past harvests, age bias in the operational inventory, and increases in fire frequency related to European settlement. It was possible to measure the impact on SRI of most of these factors, and it was concluded that the inventory could be used to determine the average age of stands, and the average age for most age classes. Additionally, the biases due to the various factors were relatively small with the exception of modern fire suppression, which increased the SRI derived from the inventory data. When aggregated, the sum of these biases are positive such that the observed SRI in the inventory data should exceed the natural SRI.

In the second stage, 4.05 million hectares of productive Crown forest were analyzed after correcting for recent harvest. Four different approaches were used to derive natural age class proportions. One approach involved using the age classes of the corrected inventory, as the "natural" benchmarks. A second approach used the negative exponential equation driven by the average age of the inventory. A third approach fitted three families of curves, a generic "best fit" equation drawn from a library of thousands of possible equations, a negative exponential, and a Weibull, using the age class data from the correct inventory. A fourth approach using mixed distribution curves to deal with the disjuncts visible in seven variants was not pursued when disjuncts in the curves were attributed, in part, to the practice of age class midpointing during operational inventories.

These alternative approaches gave somewhat different answers, but the trend was clear. When the inventory was corrected for 40 years of harvest, seven of 15 variants in the Nelson Forest Region still could not meet BGB old-growth requirements for low-emphasis biodiversity. When a negative exponential model was used with the average

inventory age, the average SRI for the region was 156.6 years as compared to the BGB estimate of 220 years. When specific inventory age classes were fitted against negative exponential curves, the average, derived SRI value for the region was 143.9 years. A different model, the Weibull equation, yielded curves with larger adjusted R^2 values than the BGB negative exponential equation.

The analyses indicated that the BGB methodology yields larger proportions of older age classes than are contained in the local data. Three variants were within 20 years of the BGB SRI estimates, whereas five variants varied by 100+ years. One variant varied by 185 years. These discrepancies exceeded the estimates of bias determined in the first stage in the study. As well, derived SRI values from this study were within the range of the values found in 17 published studies, for 14 of 15 variants.

An average difference of 63 - 76 years separated the SRI estimates of this study from those of the BGB. Approximately 29 years could be explained by the BGB's use of maximum stand age while estimating SRIs. By comparison, this study used the mean stand age from the inventory.

The original BGB estimates of SRI are substantially higher than values obtained from corrected inventory data subjected to the same BGB methodology. Both larger initial estimates of SRI, and the choice of model (a negative exponential equation), contributed to larger old-growth requirements in the BGB. These factors may explain, in part, the widespread failure of many relatively undisturbed landscape units to meet BGB age class requirements.

In summary, this study has successfully linked the operational inventory data to the Biodiversity Guidebook and has objectively estimated natural age class proportions. While there are still differences of opinion concerning the reasons for the observed discrepancies (human-caused versus BGB methodogies), we suggest the sensitivity tests in this study explain many of the discrepancies noted by forest planners.

Several alternatives are presented to revise seral-stage requirements in the Nelson Forest Region. Modification of the BGB rules will be necessary as SRIs change. Specifically, lower age class breaks will be needed and the BGB Appendix 2 will have to be rephrased entirely if the Weibull or similar curves are adopted.

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1 INTRODUCTION

Management of biodiversity is a central requirement of the Forest Practices Code of British Columbia. The Biodiversity Guidebook (BGB) (British Columbia Ministry of Forests and Ministry of Environment 1995) was developed to translate principles of conservation biology into tangible landscape- and stand-level objectives. A major hypothesis in the BGB is that mimicking natural disturbance processes, at both the landscape and stand-level, will minimize the loss of species due to human activity. Mimicking natural processes will ensure a range of age classes and associated stand-level attributes across the forest landscape. The relationships between species diversity, stand age structures, and landscape spatial patterns are discussed and illustrated in Hunter (1990). This hypothesis has considerable logic and merit but to date it remains untested in British Columbia.

Imitating natural disturbance patterns requires a landscape disturbance model to describe the current landscape and predict future landscape conditions. The Biodiversity Guidebook has subdivided British Columbia into five natural disturbance types (NDTs). Each biogeoclimatic variant (Meidinger and Pojar 1991) was assigned to one of these NDTs. Within each NDT, critical age breaks at the biogeoclimatic zone level were assigned on the basis of expert opinion. These age class breaks reflect early, mature, and old forest conditions. To calculate the age class distribution, the BGB used a theoretical equation widely used to model seral-stage distributions in fire-dominated ecosystems.

The BGB methodology is briefly described in its Appendix 4. It consisted of consensus opinion to estimate stand replacement intervals. A quantitative evaluation of the forest cover or other inventory data was not conducted, largely because of the tight deadlines surrounding the development of the Forest Practices Code (B. Fraser, pers. comm., 1996).

In the scientific literature, most disturbance studies relevant to the Nelson Forest Region are fire history studies. This includes studies in the Canadian national parks (Johnson et al. 1990; Johnson and Wowchuk 1993), northern Idaho and Montana (Arno 1980; Barrett et al. 1991; Brown et al. 1994), eastern Washington and Oregon (Agee 1994; Lehmkuhl et al. 1994), and within the forest region (Dorey 1979; Reed 1994). These studies are based on area-based modelling, stand history derived from fire scars or stand ages, or a combination of both methods. Studies based on stand history alone are limited because: fire scars do not always record every fire in an area; fire scars are missing for stand replacement fires; stand history is limited by the longevity of trees or other stand attributes; and sampling a stand could represent a biased estimate for an area (Finney 1995; Johnson et al. 1995). A single stand of even hundreds of hectares could be an old, but relatively small, remnant in a large disturbance. For example, a 50-hectare patch of old-growth within a 500 000 hectare disturbance would have different interpretations depending on the relative age of the larger area. One would not know the significance of the small patch unless information is available for the entire study area. Area-based disturbance studies usually include stand sampling. This approach, using landscape plus stand information, has the advantage of looking at an entire landscape,

including areas up to millions of hectares. This avoids the possible biases due to sampling individual stands, which may be anomalously high or low in age. Area sampling methods do have their limits: disturbance patches may be smaller than the minimum sampling area that can be displayed within the scale of maps used; curve fitting is complex in areas where more than one disturbance regime has occurred in the past; or disturbances other than fire may significantly affect the landscape (Finney 1995). Methods for studying disturbance in fire-dominated landscapes are described in Johnson (1992), Brown et al (1994), Johnson and Gutsell (1994), and Arno et al. (1995).

Fire ecology research in and surrounding the Nelson Forest Region, combined with experience in the application of the BGB, has recently suggested that the seral-stage targets in the guidebook may not be appropriate. In February 1996, a number of experienced forest planners in the Nelson Forest Region expressed doubts as to whether the BGB seral-stage targets could be found in natural conditions in some variants. One author of this paper had concerns that the methods used to derive the seral-stage requirements for the BGB were largely subjective, and that the BGB values did not reflect published scientific data relevant to the Nelson Forest Region. Finally, in January 1997, analyses for the Kootenay Boundary Land Use Plan noted that out of 742 landscape unit/variant combinations in six (of seven) districts of the Nelson Forest Region, only 151 or 20.3% could meet the old-growth requirements of the BGB. Many of these landscape units included extensive areas relatively undisturbed by logging or other human activity.

The apparent discrepancy, between the present age class distributions in Nelson Forest Region variants and the requirements of the BGB, suggested two possibilities. First, the history of settlement may have so altered the natural landscape that the current seral-stage distribution bears no relationship to former natural conditions. Alternatively, there are inconsistencies in the data or assumptions used in the BGB.

2 REVIEW OF THEORY AND HISTORY BEHIND PRESENT SERAL STAGE REQUIREMENTS

2.1 Theory

The BGB methodology is based on the landscape history approach used to study disturbance patterns in boreal and montane forests, where fire is considered a major disturbance agent. Historical reconstruction is probably easier for fire than for other disturbance agents such as wind or insect damage. The theory and application of this landscape disturbance approach in boreal forests is described in Johnson (1992) and Johnson and Gutsell (1994). Examples of the application of this approach to landscape management issues are described in Johnson and Van Wagner (1985) and Johnson et al. (1995). There are two types of models used in this approach to landscape history. These are the negative exponential and the Weibull (Johnson 1992). The negative exponential model is a special case of the Weibull model where probability of fire is constant with stand age. The negative exponential has the advantage of simplicity. Only a single variable, the stand replacement interval (SRI), is required to generate a theoretical age

class distribution, provided the fire cycle is constant. The SRI is equal to the mean age of the forest when age is weighted by stand or polygon area.

The Weibull model allows stand mortality to vary with age but it is more difficult to use mathematically. It involves estimates of two variables, and the increased complexity allows it to fit a wide variety of data sets.

Each model has three fundamental distribution functions: 1. cumulative mortality of stands since fire or stand mortality; 2. frequency of mortality; and 3. cumulative time since fire or stand survivorship. The third distribution is also described as the frequency of **not** having a fire up to time t. The third distribution was used in the BGB and this distribution was used in this study for analyzing forest cover maps and data sets. It is the easiest to understand conceptually and most readily relates to issues in conservation biology such as old-growth retention. The formulae for this latter distribution are shown in Table 1 for both the negative exponential and the Weibull equations.

Some important concepts need to be introduced at this stage. First, these equations or models can be used in one of two manners. The equations can be used as regression tools to determine the nature of the fire ecology processes operating in a region. Age class data from these stands must be available and either the Weibull or the negative exponential models can be fitted against these data. A second use of these equations is to model hypothetical age class distributions, in the absence of age class data. Only the negative exponential model can generate age class distributions from a single value using the SRI. An estimate of this value will produce an age class distribution, but it will not match the variation or complexity of an actual forest, particularly if the fire cycle has varied over time. *This approach was used in the BGB.*

Although the Weibull is more flexible and can be fitted to more complex data sets, it cannot be used to generate hypothetical age class distributions unless two parameters are estimated.

Two additional concepts require consideration. First, a regional fire history will span hundreds of years, and changes in fire cycle have been noted in a number of studies (Masters 1990; Johnson and Larsen 1991). These changes in fire cycle can be detected as abrupt steps or disjuncts in the age class distribution curves, which are visible as changes in slope when plotted on a semi-log graph. Most fire ecologists attribute these disjuncts to climate-induced changes in the fire cycle, and it is common practice to fit mixed distribution curves (i.e., multiple curves with differing SRIs) in these cases. The age class structure of such forests are imprecisely modelled by a single Weibull or negative exponential equation.

From a practical standpoint, it is an extremely important issue. *While the BGB uses a single equation and methodology to manage the operational inventory, the leading experts suggest that the inventory data require a mixed distribution approach to accurately model the age classes.* There are divergent views, such as Rogeau (1996).

Simulation models in this study cast some doubt that these disjuncts represent changes in the fire cycle. Instead, they may be part of the random processes that drive regional climate and fire initiation in the absence of climatic change.

Finally, it should be noted that each theoretical curve, whether the negative exponential or the Weibull, comes with a variety of assumptions concerning the uniformity of the terrain in which these fires burn, the size of the area studied in relation to the size of the largest fire, and the randomness of ignition. Given that the initial studies for these equations came from the boreal and sub-boreal areas, it is clear that applying similar theoretical curves to mountainous British Columbia conditions may violate some of the basic assumptions. However, we note that the assumptions surrounding the use of negative exponential and Weibull models in this paper apply equally to the BGB. If the negative exponential or Weibull equations do not apply to the southern interior, then the basis of the seral-stage recommendations in the BGB are equally suspect. A more pragmatic question is: "Given the use of the BGB single-equation methodology, are there approaches that better model the operational age class data?"

2.2 Approach Used in the Biodiversity Guidebook

In order to evaluate the data and analyses in this paper, an understanding of the BGB approach is necessary. The BGB methodology is briefly explained in Appendix 4 of that document, but a full description of the data and methodology has not been documented or published. We have discussed the process with members of the BGB Committee (J. Parminter, pers. comm., 1996) and the method was as follows.

Initially, all biogeoclimatic variants in the province were assigned to one of five natural disturbance types (NDTs). Estimates of the SRI for each variant were obtained from various sources in the province. In some cases these estimates were based on published studies, but in most cases they were professional opinions of wildlife habitat and forest ecologists. These SRI values were based on the interval between stand-replacing events rather than average stand age.

The SRI values were averaged to produce an SRI for each NDT and BEC zone. These values were rounded to the nearest 50 years, and the rounded SRI values were used in a negative exponential equation to estimate the natural seral-stage distributions for each NDT/BEC zone combination, using various age class breaks.

At this stage the definitions for the various age class breaks between young, mature, and old age classes were established for each biogeoclimatic ecosystem classification (BEC) zone within each NDT. These age class breaks were based on inventory age classes.

Finally, a set of rules (Appendix 2 of the BGB) was applied to these natural distributions, to set the seral-stage requirements. These seral-stage requirements were intended to be used with the ages contained in the operational inventory data base.

It is important to note that the above methodology relied on expert opinion for the age class breaks, the estimates of SRI, and the choice of a model. Another source of information were the analyses for the CORE land use planning process in the Cariboo Forest Region. However, for most regions an analysis of the operational inventory was not conducted during this process.

2.3 Operational Implementation of the Biodiversity Guidebook

Currently, the BGB seral-stage requirements described in Section 2.2 are being used to evaluate and manage the proportions of different age classes in individual landscape units (LUs). Each sustained-yield management unit, whether Tree Farm License (TFL) or Timber Supply Area (TSA), is divided into a number of LUs. In the Nelson Forest Region, six TSAs are comprised of 178 LUs with an average forested area of 24 428 hectare.

In each LU, seral-stage requirements are managed by variant using the operational inventory data bases. The data bases for managing age classes in each LU are the Forest Inventory Planning (FIP) data base for TSAs, and the Segmented FIP (SEG) data base for TFLs. Both data bases are part of an extensive multi-stage operational inventory describing individual stands or polygons. The pertinent variables used in managing seral-stage distribution, are average polygon (stand) age and area. These data, when combined with BEC maps, permit a geographic information systems evaluation of the seral-stage proportions in an LU.

It is beyond the scope of this report to discuss the variety of rules and options that forest planners use to manage the seral-stage distribution in individual LUs. Planners must meet one of three different sets of seral-stage requirements, depending on the biodiversity emphasis option required for a particular LU. The draft Kootenay Boundary Land Use Plan also affects the emphasis option applied within an LU. These targets are set by the theoretical values of the BGB, but they must be met with the quantitative data from the operational inventory.

3 STUDY OBJECTIVES

We hypothesize that some of the anomalies found during implementation of the BGB are the result of linking a set of rules based on theory and expert opinion with a large-scale operational data base not originally designed for this purpose. Given the importance of the BGB in the Forest Practices Code, and its potential impact in the Nelson Forest Region, a thorough review of the uses and limitations of these data seemed wise.

The specific objectives of this study were:

1. to evaluate the age class data in the operational forest inventory, and compare them with the assumptions of the BGB;

2. to develop necessary correction factors for adjusting the age class distribution of the forest to a natural condition;

3. to refine the natural seral-stage distributions, as used in the BGB, for major variants in the Nelson Forest Region. This refinement would incorporate both quantitative data from the operational inventory and fire history research within and surrounding the region, including adjacent areas in the United States; and

4. to compare the SRIs derived from forest inventory data sets with previous studies in ecosystems within or comparable to the Nelson Forest Region.

There are major limitations to using large operational data sources for ecosystem research. However, they cover the entire operational forest, and they represent the means through which the BGB, regional land use plans, and landscape-level plans are implemented across the province. A thorough examination of the strengths and weaknesses of these data can serve as a valuable benchmark for the evaluation and implementation of the seral-stage requirements in the BGB.

4 METHODS

4.1 Disturbance Studies Applicable to the Nelson Forest Region - Review . of Literature

A literature review was conducted of disturbance studies within or near the Nelson Forest Region. For locations within the region, BEC subzone maps and BEC descriptions were used to determine the subzone or variant (Braumandl and Curran 1992). For studies in Alberta or states south of British Columbia, a BEC unit was assigned based on tree species, other vegetation species, slope, aspect, elevation, soils, proximity to British Columbia, and geographic location. For example, sites in northern Idaho and on the west side of the continental divide in Montana are very similar, if not identical, to BEC units in British Columbia. The information was summarized by subzone or variant, and compiled according to study methodology, location, disturbance types, and disturbance frequencies.

4.2 Description of the Inventory Data Sources

The data sets used for this project came from five sources. The first source consisted of the latest FIP files for the seven TSAs in the forest region. In each TSA, only Crown land containing productive forests were utilized, consisting of ownership codes 62C and 69C (or equivalent) were utilized.

The second source consisted of the latest TFL SEG files, for TFLs 3, 23, 55, and 56. Again, only productive forest land consisting of ownership codes 62C and 69C (or equivalent) were utilized.

The SEG and FIP files consist of polygons classified by a multi-stage sampling program in which aerial photo interpretation is correlated against ground inventory or temporary sample plots (TSPs) and inspections. Aerial photo classification typically uses 1 15 000 or 1:20 000 photographs in which a variety of variables, including age, are estimated for each polygon or stand. In the region, an average of 7.6% of all polygons are checked with a ground inspection or against a TSP. In TSPs, trees above a set diameter limit are measured and a number of dominants/codominants or top height trees are aged. TSPs may use either fixed-radius or prism plots.

The third source consisted of the BEC variant map lines produced by Forest Sciences in Nelson, digitized by Research Branch, Victoria, and overlaid on the forest inventory by Inventory Section, Nelson Forest Region.

The fourth source consisted of 208 inventory audit plots, established in 1994 and 1995. Audit plots consist of randomly established ground plots designed to check the characteristics assigned to polygons in the FIP and SEG data bases. These plots are established independently of the operational inventory. Not all TFLs or TSAs have been sampled, as this program is still under way. For each ground plot in the audit program, a maximum of four full-measure prism plots, and five count plots, were established in each randomly selected polygon.

The fifth source consisted of 18 125 TSPs from the Nelson and Kamloops Forest Regions. Temporary sample plots are the ground-based plots used to calibrate the photo interpretation of individual polygons. These plots provided increment-core ages for the dominant/codominant layer as well as information on veteran ages. Total ages are generally accurate to within ± 5 years.

In total, these data sources contained information pertaining to 4 050 505 ha of Crown land in the Nelson Forest Region. As a next step, these sources were used to generate EXCEL files containing the number of hectares by variant and 20-year age classes, spanning a range of 0 - 620 years for total stand age. Files were generated for variants covering at least 50 000 hectares.

Two of the 13 variants were subdivided geographically in the BGB, but these variants were treated as single units in the analyses that follow. Therefore we may speak of the 13 variants to which the quantitative curves are fitted, or the 15 BGB variants, which includes two geographically partitioned variants.

4.3 Impact of Amount of Harvest and Stand Replacement Interval on Age Class Distribution

The impact of different levels of harvesting on age class distribution was assessed by modelling. Hypothetical age class distributions were created using negative exponential equations and SRIs ranging from 100 to 250 years. Each natural age class distribution was then subjected to 5, 10, and 20% harvest. Both SRI and level of harvest ranges were

based on the ranges present in the regional inventory data. We assumed that harvest would be proportionally distributed across the older (140+ years) age classes and that all harvested areas would enter the youngest age class.

We also ran a number of simulations to determine the effect of various reallocation schemes for distributing harvested areas back into the oldest age classes. The analyses were used to select a method for reassigning harvested areas in this study. These simulations examined the effect of taking a standard amount of harvest only from stands over 140 years of age, from stands over 200 years of age, and finally from the oldest stands in the forest. The shifts in SRIs created by these strategies allowed us to estimate the potential bias due to a specific reallocation strategy.

Collectively, these simulations were used to examine a number of strategies to modify the observed age class distribution, from a "harvested" to a "natural" state. On the basis of these simulations, we identified all harvested polygons in the data base, and proportionally reallocated them to age classes above 140 years. Both partially cut and clearcut polygons were reallocated. Areas salvage-logged following a wildfire were left in their current age classes.

4.4 Stand Age Analyses

We examined inventory audit plot data to evaluate the accuracy of total stand age estimates in the operational inventory. Regression equations were fitted to a data set of 208 regional audit plots, in which ground-sampled age was determined to ± 5 years.

In a second study, the accuracy of the audit plot ages was verified by Resources Inventory Branch, Victoria, using 1081 audit plots from the provincial program (K. Tudor, pers. comm., 1996).

Finally, the TSP/PSP data base was used to examine the differences between average stand age and maximum stand age, by variant, for the dominant/codominant layer. For variants examined in this report, the data for the dominant/codominant layer (primary layer) were summarized for mean age, maximum age, difference between maximum and mean age, and range of differences.

4.5 Mean Stand Age Analyses for the Major Variants

The mean inventory stand age, weighted by polygon area, was determined for each variant using the corrected forest inventory. These mean ages were used as surrogates for SRI with the negative exponential equation, to generate natural age class proportions.

4.6 Regression Analyses for the Major Variants

The age class data, corrected for harvest, were transformed into cumulative proportions for the 15 major BGB variants in the Nelson Forest Region, by 20-year age classes. We then fitted a large number of curves against these data using *Tablecurve 2d* - a computerized, curve-fitting software program (Jandel Scientific 1994). This software allows the user to find "best fit-minimum parameters" equations from a library of possible candidate equations.

Initially, three types of equations were fitted. A "best fit-minimum parameters" equation was fitted as a benchmark against which the fitted negative exponential and Weibull equations could be compared. If either of the two classic equations were well-matched to the regional data, we expected to see them exhibit adjusted R^2 values close to the "best fit-minimum parameters" values.

The "best fit" equation with the largest adjusted R^2 value was not selected in all cases for evaluation. Some polynomial and rational equations either extrapolated poorly, or exhibited undefined or poorly fitted regions within the range of the data. Judgement was required to pick a stable, uncomplicated curve with a high adjusted R^2 value.

In addition to the "best fit-minimum parameter" equations, negative exponential and Weibull functions were fitted for each of the variants.

As a final step, the minimum parameter, negative exponential, and Weibull equations were graphed and evaluated at 20-year intervals, from 0 to 620 years total age. These evaluations were compared to the natural seral-stage proportions used to generate Tables 3, 7, 11, and 17 of the BGB.

5 RESULTS AND DISCUSSION

5.1 Organization of Materials

The detailed analyses, data summaries, and related materials used in this project are contained in a series of appendices bound as Volume 2 of this report. Copies of this volume are on file at the Nelson Regional Office.

5.2 Exploration of Sources of Bias

5.2.1 The relative amount of harvest in the Nelson Forest Region

Appendix 1 (Volume 2) contains a summary of total area by age class for the major variants in the Nelson Forest Region. Data for all polygons regardless of harvest history are presented, as well as data in which polygons with a history of logging were reallocated proportionally to the older age classes. Table 2 summarizes relative importance and percentage harvested for major variants. Of 35 forested variants in the region, only 13

contain more than 50 000 hectares each, excluding logged polygons. These variants comprised 90% of the area in the data base. The largest variants were the ICHmw2, the ESSFdk, and the ESSFwc4, which comprised 20.9, 14.5, and 13.5% of the region, respectively. The amount of harvesting in the 13 variants range from 2.8% in the ESSFvc to 24.8% in the ESSFwm, with a regional average of 11.0%. Most variants were in the range of 8 to 17% harvest.

A grand analysis of all data has been suggested, in which supplementary data from protected areas and private land would be added to the data for the productive Crown forest. This suggestion was not undertaken. The quality and coverage of forest cover data for these areas varies greatly. In some situations, TSA land has been designated as protected areas, in which case the forest cover data are complementary with the FIP and SEG files. In other cases, small pieces of private land have been classified with the FIP system, but often large pieces of private land were skipped. Data quality varies from park to park. Accordingly, it is not possible to achieve total coverage of all forest land in the Nelson Forest Region. We chose not to dilute a homogeneous data base of known quality, and restricted our analysis to productive Crown forest in TSAs and TFLs. It was noted that the BGB makes no mention of private land considerations, and that the only data required from parks are the percentages of "old seral" by variant.

5.2.2 Simulations and corrections for harvest history

Given this level of recent harvest in the Nelson Forest Region, how was age class distribution affected? We used the negative exponential equation as a basis for modelling the effects of a wide variety of harvesting levels on various SRIs (Appendix 2 of Volume 2). These simulations are summarized in Figures 1 and 2, which illustrate the effects of harvesting in forests with natural SRIs of 150 and 250 years. The forests for each of these SRI values were harvested at 10 and 20% rates. In both cases, harvesting added area to the youngest age class, reduced area in the mature age classes, and lowered the observed SRI. For example, in forests with a natural SRI of 150 years, the observed SRI for the 10 and 20% harvest were 118 and 87 years, respectively (Figure 1). Forests with a natural SRI of 250 years had observed SRIs, for 10 and 20% harvest, of 205 and 161 years, respectively (Figure 2).

Harvest reduced the observed SRI value below natural levels. In order to reverse this negative bias, removal of harvested polygons from the youngest age classes was examined as an obvious first correction. In both examples, observed SRIs were increased when this approach was taken. The observed SRI values in the 10 and 20% harvest scenarios in a forest with a natural SRI of 150 years increased to 132 and 110 years, respectively, compared to the previous scenario where harvested polygons were retained (Figure 1). Similarly, in a forest with a natural SRI of 250 years and 10 and 20% harvest scenarios, the SRI values increased to 231 and 207 years, respectively (Figure 2). However, this procedure failed to fully restore the observed SRI values to the original, natural values, as only the inflated youngest age classes were adjusted, and not the depleted older age

classes. We therefore considered moving the harvested polygons back into the older age classes.

The operational data base does not contain information to precisely reallocate young, harvested stands back into their former age classes. It must be assumed that these harvested stands came from mature stands, but whether these stands were largely above 140 years of age, or 200 years, or some other age, cannot be precisely determined.

A third group of simulations was performed to test the sensitivity of observed SRI to the method of reallocation (Appendix 3 of Volume 2). The approach was to take a forest with a natural SRI based on the negative exponential equation, harvest the forest according to three different rules, and observe the effect on SRI. These rules were to remove stands above 140 years, above 200 years, or to remove the very oldest stands. Removals were always proportional to the size of the original, natural age classes. By observing the change in SRI as a result of these scenarios, the sensitivity of logged forests could be determined for different reallocation schemes.

We concluded that the choice of reallocation age did have an effect on the observed SRI, but this effect was relatively small. For a forest with a natural SRI of 150 years and a 10% level of harvest, the difference between choosing a 140- or a 200-year breakpoint was 5.2 years. When the reallocated area was placed in the oldest stands predicted by the negative exponential equation, the difference from a 140-year scenario increased to 11.6 years.

When a forest was examined with a natural SRI of 250 years and a 10% level of harvest, the difference between choosing a 140- or a 200-year breakpoint for reallocation of harvested stands was a 7.0 year increase in observed SRI. When the 140-year breakpoint was compared with replacing the oldest stands, the difference was an increase of 26.8 years in observed SRI.

The larger differences (i.e., 11.6 and 26.8 years) between observed and actual SRI represent maximum theoretical differences that the wrong choice of reallocation strategy can make in SRI 150 and 250 forests harvested at 10%. These values are not realistic, because they assume that all of the oldest stands in the region would be harvested sequentially. This degree of access does not exist in the region. The true bias, due to our inability to precisely reallocate logged stands back to their original age classes, is estimated at 0 to 7% as per the 140 versus 200 year choice of the breakpoint.

To summarize our findings, the effects of prior harvesting were sufficiently large that corrections must be made to the raw data. In order to correct the operational inventory for harvesting, all logged polygons were removed from the younger age classes, and proportionally reallocated to age classes over 140 years in total age. Similar reallocation strategies have been used in the Cariboo-Chilcotin (H. Armleder, pers. comm., 1996) and in the Prince Rupert Forest Region (D. Steventon, pers. comm., 1996) with identical or younger breakpoints.

The corrected and uncorrected data sets for the region were fitted to the negative exponential model. It was determined that the past 40 years of harvest decreased the regional SRI by 11.7 years (Appendix 4 of Volume 2).

5.2.3 The issue of stand age in the operational inventory

Before the results of the age class analyses are discussed, it is important to consider the accuracy of stand age as evaluated from the operational inventory and how this stand age is related to stand dynamics and natural disturbance.

Operational inventory stand ages are considered unreliable by many professionals. The operational inventory system, in which polygon ages are estimated through photo interpretation and checked against a smaller number of ground plots, has limitations for many applications. Such data are viewed as substandard for detailed fire history studies, largely because of the inherent inaccuracies of the technique, and the practice of "midpointing" of age classes (Section 5.2.6). However, the same polygon ages are being used to implement biodiversity in LUs. Therefore, the fundamental question remains: how accurate are the ages contained in the operational inventory? We expected that total ages for individual stands would be generally inaccurate, but the relationship between operational inventory (FIP) total age and true total age needed to be tested at a regional level. Furthermore, the accuracy of mean total age required testing by zone and variant. Also, how accurate were the values for individual age classes? The audit plot program provided the means to test ages in the operational inventory.

5.2.4 Mean total age versus maximum total age

Some of the present difficulties in applying the seral-stage distributions of the BGB may be related to the different definitions for stand age. In fire history studies, SRI refers to the time between stand-replacing events, and this was the value used in the BGB (J. Parminter, pers. comm., 1997). In this case, the relevant stand age would be the maximum dominant/codominant tree age in the stand plus a suitable regeneration interval (Figure 3).

The operational inventory age is considerably different. It is the average, not maximum, dominant/codominant tree age. The average age will always be less than the maximum tree age, which in turn will always be less than the time since disturbance due to regeneration delay.

Table 3 portrays the numerical differences between FIP average age and maximum total age for variants in the Nelson and Kamloops Forest Regions. While they are related, it is clear that average stand age and maximum stand age are different variables and they should not be substituted for each other. For the 13 variants analyzed in this study, the difference between the two variables ranged from 19 to 36 years by subzone, and averaged 27.8 years. Therefore, for a given stand, the operational inventory definition of age is always less than the classical SRI.

This difference becomes quite important when SRIs from the published literature are compared to the ages in the operational inventory. Most published SRIs use the oldest trees in the dominant/codominant layer and the inventory measures a different age variable. In the case of the BGB, the stand-replacing fire interval was estimated, which is equivalent to the oldest tree plus a regeneration delay. Therefore, comparing BGB SRIs or published SRIs with the inventory may result in a 19- to 36-year bias in Nelson Forest Region variants.

This difference is relevant when using operational inventory to meet the seral-stage requirements of the BGB. The BGB seral-stage proportions are based on one variable, and polygon age in the forest inventory is not equivalent. An average correction of 27.8 years appears to be necessary.

In terms of regeneration delay, the assumptions used in the BGB SRIs were not quantified. It is possible to quantify these values for regenerated stands, however. In the region, average regeneration delays are 2.4 years for planted stock and 4.4 years for naturally regenerated stands (Reichenback 199[illegible]).

5.2.5 The accuracy of age estimates in the operational inventory

Are the inventory ages accurate? For the Nelson Forest Region, 208 audit plots were analyzed (Figure 4 and Appendix 5 of Volume 2). On average, the inventory (FIP) total age for these plots was 166.8 years, whereas the true total age was 167.2 years. This general relationship was confirmed for the provincial audit plot data base in a separate, unpublished analysis of 1000+ audit plots (Appendix 6 of Volume 2). This latter analysis determined that the average FIP total age for corresponding plots was 163 years for the province, whereas the true total age was 157 years. The results for the provincial data base are broken down by BEC zone and NDT in Tables 4 and 5.

These findings support the general reliability of the inventory to predict average stand age.

When the accuracy of the total age is examined by individual age classes, the picture is different. For the regional data, the operational inventory overestimated true total age, below 211 years (FIP total age), and underestimated true age above this value. No FIP total ages above 331 years were contained in the audit plot data set. It was noted that the area contained in age classes above 340 years accounted for less than 0.2% of the operational data base.

The true ages for three of 208 regional audit plots were in the range of 500-1200 years. Apparently, very old stands are rare, perhaps existing as remnants in large, younger patches of disturbance. The provincial analysis results indicate that the inventory was reasonably accurate to 250 years total age, after which errors increased and the inventory progressively underestimated true stand age (Appendix 6 of Volume 2). In the Nelson Forest Region, this 250-year breakpoint is relevant to NDT 1 and 2 variants. On the other

hand, NDT 3 and 4 variants are good candidates for fitting equations to the age classes, provided that disjunct distributions are avoided.

Correcting the inventory age to the true total age and using negative exponential equations would increase the observed SRI by 1.4 years (for the entire regional data base, pooled) as noted in Appendix 7 of Volume 2. Given the small impact of this factor and the wide scatter of the data, we did not correct the FIP ages to true total age, on the advice of our biometrician. This yielded a regional SRI of 147.8 years based on pooled inventory data.

We conclude that the mean stand age of the present inventory is reasonably reliable if used for the Nelson Forest Region variants. Thus the mean total age value can be used with the negative exponential equation to generate seral-stage proportions, provided that the fire cycle was constant. Use of age class data above 250 years is suspect, but, in general, age class data from NDTs 3 and 4 could be fitted using regression techniques.

5.2.6 Midpointed age classes

One historical photo-interpretative method of concern is the practice of midpointing. Earlier inventories relied on age classes, and photo interpreters placed a greater value on accurate classification of species, crown closure, and height than they did on stand age. Accordingly, it was common for ages to be assigned the midpoint of an age class. This was a particular problem with age class 8 (140-240 years) and age class 9 (250+ years), which were midpointed to 200 and 300 years, respectively.

This practice became less common with the reinventory of the TSAs and TFLs. Presently there are no automatic mid-points for the Boundary, Invermere, Cranbrook, and Revelstoke TSAs. For Kootenay Lake, Golden, and Arrow TSAs, midpointing by computer was used; however, approximately 50% of the polygons for these TSAs were later reclassified without midpoints, via classifier intervention.

Has midpointing been eliminated in the reinventory? Using the regional audit plots, it is possible to see the influence of midpoints on the cumulative frequency graphs. In the upper graph of the inventory plot ages (Figure 5), a clear disjunct is visible in the 200-220 year age classes, whereas this disjunct is missing from the plot of the true ages (Figure 6). This observation is a problem for fitting age class data to some variants displaying disjuncts, but there are analytical alternatives that will be discussed in Section 5.3.

We evaluated the influence of the disjunct audit plot distribution on SRI (Appendix 8 of Volume 2). When the regional audit plot data were fitted to a negative exponential equation, the derived SRI was 174.0 years, if inventory ages were used. When true ages

were used instead of the FIP ages, the derived SRI was 175.2 years.[1] This difference of 1.2 years in the audit plot data compares well with a 1.4 year sensitivity analysis using the entire regional inventory (see Section 5.2.5).

The audit plot data confirm the general reliability of average age and age class values regardless of midpointing. The bias introduced by midpointing is part of the bias related to true stand age / FIP age, as discussed in Section 5.2.5 We do note that a general bias of 1.2-1.4 years suggests that relatively large disjuncts in the cumulative age class distributions are not cause to automatically reject curve fitting using the age class data.

5.2.7 A summary of biases associated with the operational inventory data base

Figures 7 and 8 summarize the known biases and limitations contained in the BGB and this analysis. The following points summarize how this study dealt with these factors.

1. The inventory data from private land and parks were of mixed quality. The forest analyzed consisted of productive Crown land in the TSAs and TFLs. The results are therefore applicable only to these forest lands.

2. In this study, harvesting over the past 40 years reduced natural SRIs by 11.7 years. This bias was corrected.

3. We did not adjust for the influence of harvesting prior to this period given the absence of data. We suggest the bias is roughly equal to recent harvesting. This will be discussed further in Section 5.4.1.

4. Reallocation bias associated with the choice of minimum reallocation age appears to reduce observed SRIs by 0 to 7 years. This was not corrected.

5. A regional SRI based on inventory age was 1.4 years greater than one based on true age. We did not correct for this bias in the regressions on the advice of our biometrician.

6. Bias associated with midpointing is contained in the above value. A separate analysis of the audit plot data demonstrated that data sets with large disjuncts could be fitted to negative exponential equations without large errors in SRI.

7. Adding regeneration delays for managed stands would increase SRIs by 2.4 to 4.4 years. This correction was not made.

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[1] The audit plot program stratified sampling above and below 60 years FIP total age. This stratification biases the calculation of SRIs with these data. In this case, the proper comparison is between the two derived SRI values, as a sensitivity test. These values do not represent accurate regional SRIs.

8. We briefly examined the impact of fire suppression (see Section 5.4.2). Our findings confirm two other recent studies, which note that modern fire suppression activities have increased regional SRIs by 50+ years.

9. The issue of maximum tree age versus average stand age remains. We suggest that this is not a bias with the operational inventory, but inherent in the BGB values. If the BGB overestimates, by 27.8 years, the time required for a forest to reach a given seral-stage proportion, then adjustments to the BGB are required.

In summary, when the above factors are pooled (exclusive of the maximum tree age issue), SRI estimates derived from the operational inventory are expected to exceed the true natural SRIs. Because the operational inventory is used to implement the proportions, the correct dependent variable for analysis should be an SRI based on average stand age of the primary layer - not an SRI based on actual intervals between stand-replacing disturbances.

5.3 Various Approaches to Quantitatively Deriving Stand Replacement Intervals

There are four possibilities for quantitatively generating SRIs, given the preliminary studies discussed above:

1. Use the data from the inventory (adjusted for logging) to set the natural age class proportions at various ages. This approach uses neither models nor regression to smooth the data. Instead it relies on what the inventory would contain without the past 40 years of harvest. As a baseline, this approach has much merit.

2. Use the mean inventory stand age as determined by the forest inventory, and use it to model the age classes with a negative exponential equation. Examination of the audit plots has shown that this age is reliable for most BEC zones and NDTs in the Nelson Forest Region. The problem with this approach is that the relative shapes of the curves need to be identical for all variants and zones. This is an unlikely situation. Various studies have indicated that the Weibull equation fits complex age class data better and the negative exponential may overestimate old-growth.

3. Use regression techniques to fit single equations to the corrected inventory age class data. The approach would be to fit a variety of equations, including the negative exponential and the Weibull, to the FIP age class data. This approach is quantitatively correct, but it is complicated by the observed disjuncts (regardless of cause) and the difficulty with accurate ages above 250-300 years. Although a sensitivity test with the audit plots found that a large disjunct did not substantially bias the derived SRI, we suggest that this technique may best be confined to those variants that do not display large disjuncts and for which the majority of data lies

below 250 years. This limitation would be most applicable to variants in NDTs 3 and 4.

4. Use regression techniques to fit multiple distribution curves to the data. While recommended by our senior reviewers, we are uncomfortable with this technique because midpointing effects are clearly visible in the audit plot data. The the older disjuncts cannot be presumed to be caused solely by climate, in which case fitting a second curve to a very small proportion of the older age classes would be risky.

This option was not pursued. We will suggest that the higher-order single equations used in this study are alternatives to multiple distributions. We note that the BGB does not use multiple distribution curves, and that presence of midpointing precludes fitting multiple curves to older disjuncts. Section 5.4.2 discusses further the possibilities and problems of fitting multiple distribution curves to younger portions of the age class distribution.

In each of the above cases, different age variables can be used. The operational inventory uses average stand age, whereas the BGB was derived using an estimate of the interval between stand-replacing events. Use of this latter variable with the inventory data would involve a double conversion, first correcting the inventory from average to maximum stand age, doing the SRI calculations and regressions, and then correcting back to average stand age, so that the present operational inventory can be used for forest management decisions.

We did not perform these conversions because they are circular. However, discussions concerning the BGB should note that SRIs that use average inventory ages are substantially different from SRIs calculated with maximum stand (fire history) ages. Therefore, if one uses fire history SRIs from published literature to generate proportions for use with the operational inventory, a substantial bias is inherent.

5.3.1 Use of corrected inventory values

The values for this first strategy are contained in the comparative table, Table 6, along with the BGB values. The source data are contained in Appendix 1 of Volume 2.

Upon examination, it was noted that seven of 15 BGB variants, the ESSFvc, ESSFwc4/N, ESSFwm/N, ESSFwm/S, ICHdw, IDFdm1, and IDFdm2, had substantially less old seral than is now required by the BGB for low-emphasis biodiversity. Additionally, three variants, the ESSFwc/S, the ICHmw2, and the ICHmk1, are within ±2% of the BGB's low-emphasis seral-stage requirements. Given that the BGB requirements are adjusted to represent only a fraction of natural estimates, these comparisons suggest that the BGB is based on proportions of old-growth not generally found in the region's operational inventory.

This direct approach has considerable merit when dealing with regional biodiversity strategies. It links the seral-stage requirements with the operational inventory in a manner that captures all complexities. Furthermore, it corrects the known inventory for recent logging to present a quantitative, albeit comparatively recent, baseline against which more subjective seral-stage targets can be compared. The complexities and biases of individual models are avoided.

5.3.2 Use of average stand age

Given the reliability of average stand age as measured by the primary layer, we calculated the average stand ages from the corrected operational FIP and SEG data bases. By definition, these averages become the SRIs shown in Table 6. The TSPs were not used for this purpose because they are not located randomly.

These calculated SRIs were used in the negative exponential equation to determine the seral-stage proportions for the 15 BGB variants (Table 6). Of the 15 variants, we note that three were within 20 years of the BGB values, and five (ESSFvc, ESSFwc4/N, ESSFwm/N, IDFdm1, and IDFdm2 variants) differed by more than 100 years. The ESSFwm/N variant differed by 185 years.

The average calculated SRI was 156.6 years using this approach, whereas the average BGB value, based on the tables in the BGB, was 220 years.

Using the operational inventory average ages, and correcting for harvest over the past 40 years, one can use these values to set quantitative benchmarks against which the SRI estimates of the BGB can be compared. The approach directly links the operational inventory with the BGB, in that it is applicable to all variants, except possibly the MH and SBPS BEC zones (Table 4). It is a method to quickly determine if some values from the BGB may be erroneous. Also, it may be used to explore regional biodiversity strategies based on the approach used by the present BGB.

5.3.3 Single-equation regression analyses

Appendices 9 to 11 of Volume 2 contain the graphs, equation parameters, and equation evaluations for the fitted negative exponential, the Weibull, and the minimized parameter equations for each variant. Figure 9 is a comparative example of the BGB curve and the three families of derived curves for the MSdm1 variant. Table 6 summarizes the regressions and compares them to the original "natural stand" values from the BGB.

The presence of large disjuncts in six of 13 variants, suggests that a single-equation regression approach with age class data is suspect in these cases. The variants affected include the ESSFvc, ESSFwc4, ESSFdc1, ESSFdk, ESSFwm, and ICHwk1 (e.g., Figures 10 and 11). Small disjuncts were observed in two variants, the ICHmw2 and the MSdm1. Nonetheless, of the three groups of curves fitted to the operational inventory data, the minimum parameter equations produced the best fit in seven cases, followed by the

Weibull equation in the remaining six cases. The negative exponential curve generally produced the least satisfactory fit.

When only the seven variants with small or no disjuncts were analyzed, this trend was similar. In four cases the Weibull produced largest adjusted R^2 values whereas the minimum parameter equations produced the best fit in the remaining three cases. Again, the negative exponential curve produced the least satisfactory fit.

The SRI values obtained from this analysis closely resembled the values from Section 5.3.2, in which average variant ages were used. For the 13 variants analyzed, the fitted negative exponential equations produced an average SRI of 143.9 years, compared to the average of 220 years based on values in the BGB. When average variant ages were used, an SRI of 156.6 years was obtained.

5.3.4 Choosing a model

In this study we examined three approaches using the inventory data to determine natural seral-stage proportions in BEC variants. We can summarize the results as follows:

1. The direct use of corrected inventory proportions was the most accurate, because the data were not smoothed by a model. This approach will minimize discrepancies between corrected natural proportions and the inventory. It eliminates the bias from the choice of model and avoids the issues surrounding multiple distribution / single distribution approaches. The technique does not generate an SRI.

2. The use of average inventory age with a negative exponential equation duplicates present BGB methodology. It can be applied provincially in all zones except possibly the MH and SBPS. While the SRIs and proportions generated are substantially more accurate than related estimates now contained in the BGB, the young and old seral proportions can greatly exceed the natural levels found in the corrected inventory.

3. The use of age class data in various regression models runs into the problem of disjunct curves and increasing error with age determinations above 250 years. Single curves can be fitted in seven variants with no or small disjunct age class distributions. The use of negative exponential curves fitted to age class data produce nearly identical results as compared to using negative exponential curves driven by average stand age. The Weibull and minimum parameter curves provide more accurate estimates than the negative exponential model, but they still overestimate the current old seral proportions in most of the 13 variants.

4. Of the two classical fire ecology age class distribution models, the Weibull function provided a consistently better fit against the age class data than did the negative exponential equation.

5 We note that, of the regression methods tested, all of them, as well as the BGB, overestimated the proportions of old seral as compared to the inventory data. It was also observed that the "minimum parameter" and Weibull equations often differ considerably in shape from the negative exponential equation used in the BGB. These equations reduced the proportions of predicted early and old seral proportions. These equations also yielded higher adjusted R^2 values than the negative exponential form.

Multiple distribution curves are the traditional next step if disjunct distributions are noted. This approach may not work well with inventory data, and it may not be necessary. We note that a number of the "minimum parameter" curves selected in this study were complex, higher-order equations that fit well the complex age class distributions. These complex curves avoid the dilemma of breaking the age class data into sectors, some of which either contain few data or are confounded by midpointing effects. If more sophisticated curve-fitting methods are pursued, a number of outstanding issues need to be considered.

5.4 Outstanding Issues

5.4.1 The issues of European settlement, climate change, and very old harvesting

A fundamental issue with the preceding analytical approach is whether European settlement of the Nelson Forest Region has affected the SRIs. It is commonly accepted by the public and some forest management professionals that large areas of the southern interior were burned in the past 100 years through human carelessness, due to ignition along railways, or to assist prospecting and mining activities. Much of the historical information is anecdotal, and, in the end, we must examine the present inventory for possible clues.

If settlement fires were widespread, then the SRIs and curves since about 1880 onward represent an unnatural state, and we should see a disjunct curve similar to the breaks occurring approximately 200-220 years BP in the ESSF. In order to more clearly detect these breaks, we produced semi-log plots of the data for 13 variants as contained in Appendix 12.

Examples of a disjunct curve and its semi-log plot are shown in Figures 10 and 11. In these semi-log graphs the 200-220 year BP breaks in the ESSF curves are clearly detectable, but in only one of the 13 variants, the MSdm1, was a minor break in slope visible at approximately 80 years BP. We do, however, note a consistent break in slope approximately 40 years BP when SRIs increase. This break approximates the initiation of modern fire suppression techniques.

Given the presence of midpoints caused by photo interpretation, a regional semi-log plot was also produced using the audit data (Figure 12). Several apparent changes in slope are noted, at 50, 200, and 300 years BP. We do not see a change in slope at 120 years, which would coincide with European settlement.

Published fire ecology studies from the national parks may provide some explanation as to why a larger impact from European settlement is not seen in the data. Climate is the main control of fire regime. Climate determines the fuel loading and distribution, the frequency of natural ignition agents such as lightning, and ultimately the type, extent, duration, and severity of the fires (Van Wagner 1985; Johnson 1992; Agee 1994). Changes in fire regime patterns can also be correlated to past changes in global climate. For example, several studies in the national parks of the Canadian Rockies have documented changes in fire frequency during the 1700s that correspond to global climate shifts during the Little Ice Age (Johnson et al. 1990; Weir et al. 1995). Studies in the national parks have also demonstrated that lightning-caused fires have a far greater impact than human-caused fires on landscape patterns. Also, the influence of post-European activity on the fire regime is minor. For example, a study in Glacier National Park found that lightning caused more fires than did humans, and that the resulting fires burned far more area than human-ignited fires (Johnson et al. 1990). This result was true for the past few decades and for the last century during the period of earliest European activity. Although human-caused fires have been documented in the national parks, these fires occurred at times when significant lightning-caused fires occurred in relatively inaccessible areas of the park. This supports the concept that climatic conditions determine the fire frequency and extent, irrespective of the ignition source. A similar study in the Kananaskis Valley found that fire frequency before and after 1883 was approximately the same (Johnson and Fryer 1987). This date was the start of significant European activity in the valley.

Major fire activity in the national parks and much of northern North America is caused by drought conditions lasting for several weeks to a few months, followed by lightning and strong winds (Johnson and Larsen 1991; Johnson 1992; Johnson and Wowchuk 1993). The droughts are created when stationary, high-pressure blocking systems develop in the north-central part of North America. This results in large areas remaining warm and dry for several weeks or longer. The breakup of the high-pressure system often has high-intensity lightning storms (causing ignition) followed by strong winds (spreading the fire). The result is a catastrophic fire that can burn from valley bottom to alpine. This mechanism is also acknowledged as a major controlling factor in fire studies in the United States (Barrett et al. 1991). Other studies in the Rocky Mountain areas of the United States have correlated major past fire events with climatic drought. For example, Lehmkuhl et al. (1994) note that the largest fire events in the past 500 years in eastern Washington and Oregon occurred during the three worst drought periods: 1910-1936, 1650-1700, and 1850-1900. Heinselman (1985) notes that a few major fires following drought create most of the fire-maintained landscapes. He notes that in the northern Rockies of the United States, most of these fire events followed significant droughts during: 1981, 1967, 1961, 1910, 1892, 1889, 1871, 1864, 1846-1847, 1824, 1803, 1758, 1714, 1695, and 1667. Fire suppression has been suggested as a factor affecting the fire regime in some areas (McCune 1983; Barrett et al. 1991). However, even though Barrett et al. (1991) felt that fire suppression had an impact on the fire regime in one area of Glacier National Park, Montana, in two other areas of the park, fire suppression was not considered to have altered the fire regime. From these and other articles, one can draw a

number of conclusions: significant alterations in fire frequencies have not resulted from human-caused ignitions; climate has determined the conditions for successful ignition and spread of fires; apparently increased fire activity due to humans has occurred when climatic conditions were suitable; and lightning-caused fires were burning significant areas at the same time that humans were causing fires. With respect to fire suppression, climate has also determined how much impact humans have in terms of extinguishing fires. Recent improvements in fire-fighting technology, availability of resources, and access may have increased the abilities of humans to control the fires. Alternatively, short- or long-term climatic changes have probably modified fire frequency during the last few decades and affected the degree of success in fire suppression.

In the operational inventory, we cannot attribute disjuncts solely to climate. Midpointing was demonstrated in Section 5.2.6, and it is incorrect to attribute the visible disjuncts to climate alone. Conversely, when the corrected audit plot data are examined, major changes in slope occur at 200 and 300 years that cannot be attributed to midpointing. These disjuncts are likely changes in the fire cycle, although Rogeau (1996) demonstrated with simulation models that similar breaks in slope occur at random during stable fire cycles.

It is likely that the visible disjunct at 220 years BP in the operational inventory is caused by midpoints confounded by a climatic or random process at 200 years BP. We suggest that the presence of midpointing precludes any attempt to calculate a second SRI for the older portion of the age class distribution beyond the disjunct, given the few data contained in the age classes above most disjuncts.

In conclusion, fire ecology studies from the adjacent national parks and from the United States indicate that the influence of European settlement on fire frequency and age class data should be minor. The regional semi-log plot of the audit data confirms that 50-200 years BP the fire cycle was constant, suggesting that there is no rationale to confine SRI calculations to pre-European settlement age classes. Likewise, the semi-log plots of the inventory data for each of 13 variants exhibited only one case of a small change in slope between 1880 and 1900.

The effect of European settlement on SRI may have been buffered by the extremely large area used in this study. As an example, 40 years of industrial harvesting reduced the regional SRI by only 11.7 years. If an SRI bias due to settlement is present in the current inventory data, it is not visible. Therefore, we did not specifically correct for this factor given the lack of data, the absence of a visible effect in the curves, and the counter-balancing biases of other factors.

5.4.2 The issue of fire suppression

The effect of modern fire suppression may be visible as a change in slope in the regional semi-log plot of the audit data, starting about 50 years BP (Figure 12). Large effects of fire suppression on SRIs have been documented by Masters (1990) and McCune (1983).

These studies found recent SRIs of thousands of years due to fire suppression, with the cautionary note that limited data were available to do proper curve fitting. Since the 1940s, fire suppression is presumed to have increased the SRI of many variants by increasing the proportions of mature and old stands, and reducing the proportion of younger age classes. When a regional SRI is calculated from these data, the entire audit plot data base yields an SRI of 175.2 years, whereas the SRI is reduced to 115.6 years if the 50 years of fire suppression is removed from the audit plot data base (Appendix 13 of Volume 2). This 60-year increase in SRI is similar to the 50-year increase in SRI caused by fire suppression in Banff and Assiniboine National Parks (Rogeau 1996). In the Cariboo, unpublished work by the CORE Biodiversity Strategy Committees notes substantial positive SRI increases due to this factor (J. Parminter, pers. comm., 1997). In NDT 2, this effect raised the average SRI for the ESSF by 41 years. Similarly, in NDT 3, this effect raised the average SRIs for the ESSF and MS by 41 and 103 years, respectively. The methods used by the Strategy Committee are not fully documented.

Fire suppression appears to have the largest effect of any bias examined in this study, and its size corrects for existing negative biases such that the present derived SRIs from inventory data will exceed the natural SRIs. Therefore, the SRI values derived in this study, while lower than the BGB values, are still likely higher than required when a single-equation methodology is preserved.

This point highlights the dilemma related to multiple distributions. Although the BGB natural seral-stage requirements are based on a single curve, the regional semi-log plots indicate that three to four SRIs can be derived for each variant. The 0-50 and 50-200 years BP intervals can be fitted but the reliability of older periods is questionable because of midpointing. Therefore it is possible to reduce the derived SRIs in this study by concentrating on the 50-200 year BP period, before the advent of modern fire suppression. However, the BGB utilizes a single curve for all operational age classes, and this is the comparison presented in this study.

5.4.3 The issue of stand age versus ecosystem age

A major argument for greater SRIs lies in the concept that, in the absence of a stand-replacing event, succession over long periods can replace the trees in the stand (Rogeau 1996). Under these circumstances, the age of the undisturbed stand can exceed the age of the oldest trees present in the stand. Unfortunately, there are few data that allow us to ascertain the true total age or existence of such stands in the Nelson Forest Region, nor are there reliable methods to estimate the relative proportions of these stands in order to adjust the existing operational inventory. We note that this concept was not incorporated into the present BGB.

For completeness, we will discuss this concept. If truly ancient stands have evolved over very long periods, some evidence should be present in the form of ancient tolerant species. The audit plots do provide some clues as to the relative rarity of extremely old trees. Provincially, only nine of more than 1000, 60+ year old stands were found to be older than

500 years total age. In the Nelson Forest Region, only three of 208, 60+ year old stands were similarly aged. Given the potential age of the tolerant species of this region, it is surprising that there are not more of these older stands in audit plots, if either older stands or greater SRIs were present in the landscape. For example, given a 220-year SRI, 10.3% of stands should be older than 500 years total age. Given 250- and 350-year SRIs, the proportions increase to 13.5 and 24%. Yet the actual proportion, albeit biased due to the incomplete distribution of the audits to date, is much less, at 1.5%, which compares well with the value of 3.1% predicted from the average SRI value of 144-157 years derived in this study.

Relatively old trees do occur in many stands, but may represent a relatively small proportion of the stand, and we again point out that the inventory is based on the mean age of the primary layer. For example, the mean stand ages for the IDFdm1 and the ICHmw2 from TSPs were 118 and 122 years, respectively (Table 3). However, the oldest trees sampled in the dominant/codominant layer were 315 and 605 years for the IDFdm1 and the ICHmw2, respectively. This observation suggests that, while large, old trees are found in many stands, most of the stands are composed of younger trees. It demonstrates how different conclusions are obtained when mean ages are used interchangeably with maximum ages.

Our conclusion is that ancient stands developed through successional pathways are rare, and disturbance, by whatever processes, is more frequent, or else we would be seeing more ancient stands in the audit plots, particularly in the ICH.

In terms of management, one should also note that there are two schools of thought on old-growth management, one linked to age, and one linked to stand characteristics (Oliver and Larson 1990). The latter view holds that stands with specific structural characteristics, such as average stand diameter, number of large stems per hectare, and number of snags per hectare, can meet the definition of old-growth regardless of age. This approach is mentioned in the BGB as an alternative approach to managing for old-growth, namely, if a stand can be grown to resemble old-growth, age is irrelevant. We mention this concept because managed forests will likely require less time to generate stands with large structures, not more time as in the case of ecosystem replacement intervals.

5.5 Comparison of the Quantitatively Derived Stand Replacement Intervals with Existing Literature and the Biodiversity Guidebook

The results of the literature review of past disturbance studies are included in Appendix 14 of Volume 2 and summarized in Table 7. The following is a comparison between literature review results and the corrected SRI values calculated for variants in this study. Eleven of the 15 variants in this study have SRIs within the range of variation found for studies with the same or comparable ecological units. Given the literature does not cover the MSdm1, we have assumed that the disturbance regime should be similar to the MSdk. Both variants have similar climate, tree species, and disturbance regime (Braumandl and Curran 1992). The group of 11 variants includes ESSFwc4/N, ESSFwc4/S, ESSFwm/N,

ESSFwm/S, ESSFdk, ICHmw2, ICHmk1, ICHdw, IDFdm2, MSdk, and MSdm1. For example, the ESSFwc4/N has a corrected SRI of 170.2 years. One study that includes this variant found a lower confidence interval for stand replacement of 35 years in Kootenay Lake TSA (Reed 1994). The maximum value for disturbance frequency within subalpine spruce stands, comparable to the ESSFwc4, is an upper confidence interval of 200 years (Brown et al. 1994). This study was located in the Selway-Bitterroot Wilderness of Idaho-Montana.

Three of the 15 variants in this study had corrected SRIs that are greater than all values from the literature: the ESSFvc, ICHwk1, and IDFdm1. A good example is the IDFdm1. Two studies with stands comparable to this variant found that the primary disturbance activity was surface fires with a periodicity of 24 years or less (Barrett 1988; Agee 1994). For stands comparable to the IDFdm1, fires with stand-replacing potential have occurred with a frequency of 41 years in the Salmon River drainage of Central Idaho (Barrett 1988).

One of the 15 variants in this study, the ESSFdc1, had a corrected SRI less than the literature values. The only study with ecosystems comparable to the ESSFdc1 yielded a frequency for stand replacement fires of 250 years (Agee 1994).

In summary, it appears that the corrected SRIs in this study are reasonable, since 14 of the 15 BGB variants studied displayed derived values that are either within the range of, or greater than, those found in 17 published studies.

5.6 Factors to Consider Prior to Altering Seral-stage Requirements of the Biodiversity Guidebook

This study examined how the operational inventory can be used to estimate the natural seral-stage proportions of individual variants. These natural proportions can be subjected to a number of rules, as specified in Appendix 2 of the BGB, to calculate final seral-stage requirements. While we did examine how these changes in natural proportions would translate into changes in the seral-stage requirements, the present study does not describe these simulations. We felt that changes in the values for SRI and other disturbance parameters would require a review or revision of the rules used for operational application. Nonetheless, some general observations are appropriate.

The present BGB is based on a negative exponential equation, which was used to set the rules for maximum allowable changes in different seral-stages. Although the fitted negative exponential equations derived in the current project did not provide the best adjusted R^2, the use of either this equation with the average stand age, or fitted to the age class data, would be consistent with the rules and methods contained in the present BGB.

If Weibull or minimum parameter curves are selected, the rules governing early seral requirements (in particular) and other seral-stages (in general) will have to be reconsidered, as the shape of these latter curves differs considerably from the shape of

negative exponential equations. The present BGB rules were established when working with equations that predicted much larger proportions of forests under 40 years total age. Partly because of the nature of Weibull functions, and partly because of the disturbance history of our present forests, the derived values for early seral proportions in natural stands will be much lower using Weibull or minimum parameter models. A similar effect will occur with the old seral-stage.

A second point concerns the generally lower SRI values obtained in this study. One way to deal with variants displaying smaller SRIs is to shift them into different NDTs. This strategy is being suggested as a mechanism to preserve the present BGB without major modification. Unfortunately, movement of variants into different NDTs (e.g., from 4 to 3, or from 2 to 3) may preserve the present structure of the BGB, but these shifts may be of limited effectiveness. The problem is that the present structure of the BGB is quite coarse, with five NDTs containing a set of very limited SRIs (i.e., 150, 200, 250, and 350) from which all proportions are based, for the entire province of British Columbia. While it is possible to shift some variants from one NDT to another, in a number of cases there is no appropriate NDT, and there is little flexibility.

The analytical alternative is to create more NDTs, or simply drop the concept altogether, and focus on assigning SRIs for each variant, perhaps in 20-year-wide SRI classes. Analytically this is an easy process, and it is conceptually more appropriate in a highly diverse province such as British Columbia.

A third point concerns the value of age class break points for these NDTs. As SRIs change, the age class breaks for the mature and old seral-stages may need to change as well. This concept has not been pursued in this paper, but we will suggest that age class breaks of 20-year width should be considered for the SRI-class system, depending on the ecology and silvics of the forest types being preserved. There is no point in retaining an old seral age class break of 250 years when a variant displays an SRI of 120, since the amount of land affected by the 250-year break will be small. A more effective approach would ensure that the age class break "captures" a reasonable percentage of the landscape after the rules are applied.

One final point needs to be made with regard to Appendix 2 in the BGB. The rules used to set seral-stage targets assume a set value of 12% for old-growth in protected areas, rather than the true values. The logic surrounding this 12% deduction is not clear, as the math behind the value essentially assumes that all protected areas in the province consist *entirely* of old-growth forests. Actual old-growth data are available for protected areas in the Nelson Forest Region, and these figures can be used when Appendix 2 rules are revised.

6 RECOMMENDATIONS AND CONCLUSIONS

This study has examined a wide variety of factors inherent in using the operational inventory to manage seral-stage proportions in the Nelson Forest Region. A summary of these factors, and the manner in which the BGB and this study deal with them, is contained in Table 8. We conclude that the operational inventory can be used to quantitatively evaluate the seral-stage requirements of the BGB. Corrections for various factors are required, but in general the biases balance out, so that SRIs derived from the inventory will be larger than "natural" SRIs. The process could be duplicated in other areas of the province, and such a provincial project would provide valuable benchmarks against which the present BGB estimates could be compared.

The nature of the operational inventory makes it an awkward choice for the exact imposition of seral-stage requirements over much of the province. Although subject to ground checks, it is essentially an aerial system designed to estimate stand volumes, not age. It is somewhat of a testament to the effectiveness of the system that average stand age is relatively accurately determined, as confirmed by the audit plots. We recommend that the value of accurate age estimates be reinforced with the classifiers and inventory staff throughout the province, given this important new use of the data.

It was noted that the operational inventory contains age values for the *average* stand age, not the *maximum* stand age used in fire history studies. Therefore, the operational inventory underestimates stand age (as determined in the BGB's assumptions) by an average of 29 years in the variants examined, and the BGB values for seral-stage requirements may be biased accordingly.

Mean stand age, as determined from the operational inventory, allows one to use the same methodology used in the BGB to generate seral-stage percentages by variant. An alternative approach is simply to use the seral-stage proportions of the inventory, corrected for known logging, to examine regional biodiversity targets. At present, either approach is applicable to all variants.

Although the various single-distribution regressions used in the BGB and this study have merit, at present they can be used with predominantly NDT 3 and 4 variants, subject to certain conditions relating to disjunct distributions. In these cases we found the Weibull equation superior to the negative exponential equation, and note that the latter equation has the property of greater estimates for old-growth requirements.

In the Nelson Forest Region, these three alternative, quantitative approaches gave somewhat different answers, but the trend was clear. When a negative exponential model is driven by the average inventory age, the average SRI for the region dropped from the BGB estimate of 220 years to 156.6 years. When negative exponential curves are fitted against the age class values for all variants (including those with pronounced disjuncts), the average, derived SRI value for the region is 143.9 years. Finally, we can also use the corrected inventory proportions against the BGB's seral-stage requirements,

comparatively, to note that seven of 15 variants could not meet present low-emphasis biodiversity, old-growth requirements, when the effects of the past 40 years of harvest were removed.

The above comparisons indicate that three variants are within 20 years of the BGB SRI estimates, whereas five variants vary by more than 100 years, based on using the average inventory age with the negative exponential equation.

This study also noted three to four disjuncts per variant, suggesting that multiple distribution curves may need to be considered. If 50 years of fire suppression is removed, and stands older than 200 years are discounted due to the predominance of midpointing, a 150-year interval without major disjuncts remains. This interval may be too restricted in terms of the acceptable interval for fire ecology studies, which in theory should span three fire cycles (Rogeau 1996).

Given the difficulties being experienced with field implementation of the BGB in the Nelson Forest Region over the past 18 months, we suggest that revisions are necessary to deal with large overestimates of SRI in some regional variants. These revisions should be made on the basis of data analysis to preserve the philosophical and theoretical intentions of the BGB. The operational inventory is surprisingly robust, as verified by the audit plot system, and there are few obstacles toward using it for this purpose.

Some professionals may suggest that the operational inventory is biased, and it cannot represent the original forest condition. However, the present provincial approach to managing biodiversity uses the same data to implement the BGB, and these data suggest that the original estimates of SRI were conservative. First, the difference between the estimated and derived SRI values is large, averaging 63-77 years. Second, there may be an inadvertent 28.8-year bias in the use of the BGB SRIs based on maximum age, when the inventory uses average stand age. Third, we have explored the potential biases in the operational inventory and they do not explain the observed differences between the BGB and this analysis. Fourth, the audit plot system provides confirmation of the operational inventory age data.

The final argument supporting the rationale to revise the BGB seral-stage requirements for the Nelson Forest Region lies in the published studies in and around the region. In 14 of 15 variants, the derived SRIs in this study are within the range of, or greater than SRIs in 17 published studies.

We suggest using the inventory data, corrected for the past 40 years of logging, as a benchmark against which the BGB rules are applied. The use of the corrected data will negate the biases and dilemmas incurred when single equations are used to model a complex natural system, in which a single, natural fire cycle does not exist. This approach would avoid overestimating young and old seral-stage proportions, and it would avoid truncating the existing data into a narrow interval to accommodate mixed distributions, which in turn violates other assumptions about these models.

If the BGB Committee wishes to retain the present single-equation approach to the BGB, the mean stand age can be used in the negative exponential in all Nelson Forest Region variants. Additionally, seven variants have sufficiently robust age class data that either fitted negative exponential or (preferably) Weibull equations can be used.

If actual or derived natural levels are accepted, there is still the matter of modifying the rules to reflect the new curves. This will not be a simple process, but some changes are warranted. The most conservative scenario would be the use of derived negative exponential equations, with some changes in definitions as to age class breaks. Movement of variants to other NDTs has some limitations. This latter approach would be the most liberal in terms of preservation of older age classes.

With the Weibull and "minimum parameter" families of curves, application becomes more complicated. In these cases, the younger age classes are limiting due to the present rules designed for negative exponential equations. Also, the rules for old-growth were developed with the impression that 10-25% was present, not 3%. Changes in approach will be necessary at both extremes.

Although BGB values based on expert opinion are a necessary starting point when data is unavailable, revision through the acquisition and analysis of new data must be accepted to maintain scientific credibility for the process. Some of the BGB values are appropriate for the Nelson Forest Region, and others at variance with the above procedures may still be appropriate for other areas of the province. For example, although this study has found major deviations in SRI values for some variants, the BGB values may be close to the true values in other forest regions such as the Kamloops or Cariboo Regions. These discrepancies may simply reflect regional differences in climate and other factors that control disturbance processes.

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TABLE 1. Two classic stand survivorship models

Model	Equation[1]	Comment
Negative exponential	$Y = \exp(-t/b)$	the risk of burning remains constant over time
Weibull	$Y = \exp(-t/b)^c$	the risk of burning changes over time

[1] Where Y = proportion of forest greater than age t
t = age of forest stands
b = expected recurrence time of fire in years
c = shape parameter

TABLE 2. Total area and percentage harvested for 13 variants in the Nelson Forest Region

Major variants in the NFR[1]	Total area in FIP files (ha)	Percentage of region	Area in FIP files, excluding harvested polygons (ha)	Percentage of variant harvested
ESSFdc1	58 933	1.5	53 562	9.1
ESSFdk	586 986	14.5	534 709	8.9
ESSFvc	198 644	4.9	193 071	2.8
ESSFwc4	546 243	13.5	498 850	8.7
ESSFwm	270 563	6.7	203 447	24.8
ICHdw	201 727	5.0	185 459	8.1
ICHmk1	134 676	3.3	119 531	11.3
ICHmw2	847 553	20.9	716 162	15.5
ICHwk1	178 780	4.4	150 905	15.6
IDFdm1	66 263	1.6	55 267	16.6
IDFdm2	139 282	3.4	116 213	16.6
MSdk	348 015	8.6	294 488	15.4
MSdm1	69 875	1.7	58 303	16.6
Variant total	3 647 537	90.0	3 179 970	Average 12.8
Regional total	4 050 505		3 604 520	Average 11.0

[1] Variants with >50 000 ha.

TABLE 3. Age data for primary layer[1] of temporary and permanent inventory sample plots–Kamloops and Nelson Forest Regions

Variant	Sample size (n)	Maximum age of primary layer (yr)	Mean age of primary layer (yr)	Difference[2]	
				Mean (yr)	Range (yr)
ESSFdc1	242	205(4.5)[3]	176(3.9)	29(2.2)	0–199
ESSFdk	976	210(2.7)	182(2.4)	28(1.0)	0–345
ESSFvc	57	218(10.1)	185(9.0)	34(4.8)	1–176
ESSFwc4	652	197(3.3)	161(2.6)	36(1.6)	0–275
ESSFwm	371	205(4.8)	171(3.8)	34(2.1)	0–301
ICHdw	416	108(2.9)	88(2.1)	19(1.5)	0–302
ICHmk1	412	148(4.4)	119(3.0)	28(2.3)	0–505
ICHmw2	1524	147(2.4)	122(1.9)	25(1.0)	0–297
ICHwk1	507	184(5.1)	159(4.4)	25(1.6)	0–305
IDFdm1	235	152(4.6)	118(3.3)	34(2.9)	0–518
IDFdm2	135	115(5.1)	92(4.2)	22(2.2)	0–131
MSdk	448	136(4.1)	113(3.2)	23(1.9)	0–416
MSdm1	256	141(4.9)	116(3.5)	25(3.3)	0–665

[1] Dominant/codominant tree layer.
[2] Maximum stand age minus mean stand age.
[3] Mean with standard error in brackets.

TABLE 4. Provincial comparison of inventory age to audit age by BEC zone[1]

BEC zone	Inventory age (yr)	Audit age (yr)	Difference (yr)	n
AT	211	211	0	26
BWBS	111	101	-10	68
CWH	215	221	6	235
ESSF	190	173	-17	174
ICH	153	147	-6	202
IDF	151	142	-9	97
MH	265	303	38	30
MS	136	127	-9	60
PP	156	141	-15	3
SBPS	133	93	-40	21
SBS	144	141	-3	164
SWB	93	82	-11	1
Average	163	157	-6.3	1081

[1] After Tudor (1997).

TABLE 5. Provincial comparison of inventory age to audit age by natural disturbance type[1]

NDT	Inventory age (yr)	Audit age (yr)	Difference (yr)	n
1	230	244	14	229
2	175	161	-14	312
3	132	122	-10	333
4	152	143	-9	97
5	211	211	0	32
Average	180	176.2	0	1003

[1] After Tudor (1997).

TABLE 6. Natural age class distributions for the Biodiversity Guidebook and various modelling scenarios, using corrected inventory age class data from the Nelson Forest Region

Variant	NDT	Modelling scenario	SRI (yr)	Adjusted R^2	"Natural" proportions by seral stage[1]		
					Early	Mature + Old	Old
ESSFdc1	3	Biodiversity Guidebook	150	–	76.6[2]	44.9	39.3
		Corrected inventory	–	–	99.0	50.6	44.9
		Average inventory age–negative exponential	162.1	–	78.1	47.7	42.2
		Fitted age classes–negative exponential	149	0.9245	76.5	44.7	39.1
		Fitted age classes–Weibull	–	0.9859	91.9	55.3	45.8
		Fitted age classes–minimum parameters	–	0.9649	94.7	61.1	50.2
ESSFdk	3	Biodiversity Guidebook	150	–	76.6	44.9	39.3
		Corrected inventory	–	–	94.1	46.5	39.8
		Average inventory age–negative exponential	151.3	–	76.8	45.2	39.6
		Fitted age classes–negative exponential	137.8	0.9467	74.8	41.8	36.2
		Fitted age classes–Weibull	–	0.9925	88.8	49.2	40.2
		Fitted age classes–minimum parameters	–	0.9911	88.8	49.7	41.3

TABLE 6. (continued)

Variant	NDT	Modelling scenario	SRI (yr)	Adjusted R^2	"Natural" proportions by seral stage		
					Early	Mature + Old	Old
ESSFvc	1	Biodiversity Guidebook	350	–	89.2	71.0	49.0
		Corrected inventory	–	–	94.3	85.6	13.1
		Average inventory age—negative exponential	225.4	–	83.7	58.7	33.0
		Fitted age classes—negative exponential	221.5	0.7767	83.5	58.2	32.4
		Fitted age classes—Weibull	–	0.9720	100.0	96.5	22.1
		Fitted age classes—minimum parameters	–	0.9915	91.8	89.9	12.7
ESSFwc4/N	1	Biodiversity Guidebook	350	–	89.2	71.0	49.0
		Corrected inventory	–	–	95.7	59.4	9.7
		Average inventory age—negative exponential	180.5	–	80.1	51.4	25.0
		Fitted age classes—negative exponential	170.2	0.9084	79.1	49.4	23.0
		Fitted age classes—Weibull	–	0.9828	94.8	64.8	17.0
		Fitted age classes—minimum parameters	–	0.9912	95.9	59.7	17.7

TABLE 6. (continued)

Variant	NDT	Modelling scenario	SRI (yr)	Adjusted R^2	"Natural" proportions by seral stage		
					Early	Mature + Old	Old
ESSFwc4/S	2	Biodiversity Guidebook	200	–	81.9	54.9	28.7
		Corrected inventory	–	–	95.7	59.4	9.7
		Average inventory age—negative exponential	180.5	–	80.1	51.4	25.0
		Fitted age classes—negative exponential	170.2	0.9084	79.1	49.4	23.0
		Fitted age classes—Weibull	–	0.9828	94.8	64.8	17.0
		Fitted age classes—minimum parameters	–	0.9912	95.9	59.7	17.7
ESSFwm/N	1	Biodiversity Guidebook	350	–	89.2	71.0	49.0
		Corrected inventory	–	–	96.4	57.2	5.4
		Average inventory age—negative exponential	165.1	–	78.5	48.3	22.0
		Fitted age classes—negative exponential	153.1	0.9247	77.0	45.7	19.5
		Fitted age classes—Weibull	–	0.9890	92.9	57.8	12.3
		Fitted age classes—minimum parameters	–	0.9966	94.2	55.6	10.5

TABLE 6. (continued)

Variant	NDT	Modelling scenario	SRI (yr)	Adjusted R^2	"Natural" proportions by seral stage		
					Early	Mature + Old	Old
ESSFwm/S	2	Biodiversity Guidebook	200	–	81.9	54.9	28.7
		Corrected inventory	–	–	96.4	57.2	5.4
		Average inventory age—negative exponential	165.1	–	78.5	48.3	22.0
		Fitted age classes—negative exponential	153.1	0.9247	77.0	45.7	19.5
		Fitted age classes—Weibull	–	0.9890	92.9	57.8	12.3
		Fitted age classes—minimum parameters	–	0.9966	94.2	55.6	10.5
ICHdw	3	Biodiversity Guidebook	150	–	76.6	51.3	39.3
		Corrected inventory	–	–	97.9	36.7	11.2
		Average inventory age—negative exponential	117.5	–	71.1	42.7	30.4
		Fitted age classes—negative exponential	100.5	0.9005	67.2	37.0	24.8
		Fitted age classes—Weibull	–	0.9957	93.0	40.8	10.5
		Fitted age classes—minimum parameters	–	0.9926	93.2	45.8	16.2

TABLE 6. (continued)

Variant	NDT	Modelling scenario	SRI (yr)	Adjusted R^2	"Natural" proportions by seral stage		
					Early	Mature + Old	Old
ICHmk1	3	Biodiversity Guidebook	150	–	76.6	51.3	39.3
		Corrected inventory	–	–	96.9	35.7	16.5
		Average inventory age—negative exponential	118.6	–	71.4	43.0	30.7
		Fitted age classes—negative exponential	101.4	0.9176	67.4	37.3	25.2
		Fitted age classes—Weibull	–	0.9887	88.8	40.9	15.3
		Fitted age classes—minimum parameters	–	0.9786	91.5	49.0	19.6
ICHmw2	2	Biodiversity Guidebook	200	–	81.9	60.7	28.7
		Corrected inventory	–	–	95.4	49.2	8.2
		Average inventory age—negative exponential	144.9	–	75.9	50.2	17.8
		Fitted age classes—negative exponential	128.8	0.9491	73.3	46.0	14.4
		Fitted age classes—Weibull	–	0.9895	86.8	54.1	7.0
		Fitted age classes—minimum parameters	–	0.9918	92.5	53.5	10.3

TABLE 6. (continued)

Variant	NDT	Modelling scenario	SRI (yr)	Adjusted R^2	"Natural" proportions by seral stage		
					Early	Mature + Old	Old
ICHwk1	1	Biodiversity Guidebook	250	–	85.2	67.0	36.8
		Corrected inventory	–	–	93.9	79.0	29.7
		Average inventory age—negative exponential	227.9	–	83.9	64.5	33.4
		Fitted age classes—negative exponential	226.3	0.8495	83.8	64.3	33.1
		Fitted age classes—Weibull	–	0.9734	98.8	89.5	35.1
		Fitted age classes—minimum parameters	–	0.9826	93.0	83.4	39.3
IDFdm1	4	Biodiversity Guidebook	250	–	85.2	67.0	36.8
		Corrected inventory	–	–	99.0	55.4	0.1
		Average inventory age—negative exponential	135.5	–	74.4	47.8	15.8
		Fitted age classes—negative exponential	120.6	0.9042	71.8	43.6	12.6
		Fitted age classes—Weibull	–	0.9976	93.8	58.0	0.9
		Fitted age classes—minimum parameters	–	0.9972	95.1	59.7	0.6

TABLE 6. (continued)

Variant	NDT	Modelling scenario	SRI (yr)	Adjusted R^2	"Natural" proportions by seral stage		
					Early	Mature + Old	Old
IDFdm2	4	Biodiversity Guidebook	250	–	85.2	67.0	36.8
		Corrected inventory	–	–	97.6	46.6	0.3
		Average inventory age—negative exponential	126.8	–	72.9	45.4	13.9
		Fitted age classes—negative exponential	111.2	0.9127	69.8	40.7	10.6
		Fitted age classes—Weibull	–	0.9968	91.8	50.7	0.5
		Fitted age classes—minimum parameters	–	0.9955	93.5	53.2	0.2
MSdk	3	Biodiversity Guidebook	150	–	76.6	51.3	39.3
		Corrected inventory	–	–	96.6	41.2	21.8
		Average inventory age—negative exponential	124.1	–	72.5	44.7	32.4
		Fitted age classes—negative exponential	107.9	0.9300	69.0	39.6	27.3
		Fitted age classes—Weibull	–	0.9918	87.7	46.2	22.8
		Fitted age classes—minimum parameters	–	0.9944	93.3	43.6	21.9

TABLE 6. (concluded)

Variant	NDT	Modelling scenario	SRI (yr)	Adjusted R^2	"Natural" proportions by seral stage		
					Early	Mature + Old	Old
MSdm1	3	Biodiversity Guidebook	150	–	76.6	51.3	39.3
		Corrected inventory	–	–	99.1	37.2	25.5
		Average inventory age—negative exponential	123	–	72.2	44.4	32.0
		Fitted age classes—negative exponential	106.6	0.9237	68.7	39.1	26.9
		Fitted age classes—Weibull	–	0.9818	86.6	45.0	22.4
		Fitted age classes—minimum parameters	–	0.9846	94.3	44.3	22.3
Average SRI		Biodiversity Guidebook	220.0				
		Average inventory age—negative exponential	156.6				
		Fitted age classes—negative exponential	143.9				

[1] Percentage of stands greater than the lower age of seral stages defined in the Biodiversity Guidebook.

[2] Percentage of all stands >40 years total age. Note that the Biodiversity Guidebook uses <40 years, or 100 minus the value in this table. For example, in the ESSFvc, early seral would be 100% - 76.6% = 23.4%.

TABLE 7. Summary of fire frequency studies in and surrounding the Nelson Forest Region[1]

Subzone/ variant[2]	NDT	Fire types	Fire frequency Minimum (yr)	Fire frequency Maximum (yr)	Study locations	References	Comments
ESSFdc1	3	stand replacement	250	–	eastern Washington	Agee (1994)	Review article
ESSFdk	3	stand replacement	50	180	Canadian Rockies western Montana northern Idaho	Johnson and Larsen (1991) Arno (1980) Brown et al. (1995)	Masters (1990) estimates that since 1928 fire frequency is now >2700 years. However, estimate was considered unreliable as limited data points prevented proper curve fitting.
		underburns	47	–	northern Idaho	Brown et al. (1995)	
ESSFvc	1	stand replacement	80	110	Glacier National Park, Canada	Johnson et al. (1990)	Maximum value reflects disturbance pattern from 1759 to 1988, minimum occurred during 1517–1760
ESSFwc4	1 or 2	stand replacement	35	200	Kootenay Lake TSA Idaho–Montana border	Reed (1994) Brown et al. (1994)	Minimum and maximum values represent lower and upper confidence intervals for two different studies.
ESSFwm	1 or 2	stand replacement	35	166	Kootenay Lake TSA northern Idaho–western Montana	Reed (1994) Brown et al. (1995)	Minimum value represents lower confidence interval from Reed (1994).
		underburns	47	–	northern Idaho–western Montana	Brown et al. (1995)	
ICHdw	3	stand replacement/ crown fires	55	197	western Montana northern Idaho–western Montana	McCune (1983) Brown et al. (1995)	McCune (1983) estimated a value of ~7500 years after 1910 due to effective fire suppression.
		mixed intensities	33	100	eastern Washington	Agee (1994)	Fires varied from understorey to stand replacement.
		ground fires	18	–	eastern Washington	Arno (1980)	Some of areas may approximate the ICHxw rather than the ICHdw.

TABLE 7. (continued)

Subzone/ variant	NDT	Fire types	Fire frequency Minimum (yr)	Fire frequency Maximum (yr)	Study locations	References	Comments
ICHmk1	3	stand replacement	100	500	western Montana	Agee (1994)	
ICHmk1	3	intermediate/ understorey	17	100	western Montana	Agee (1994)	
ICHmw2	2	stand replacement/ crown	35	250	Kootenay Lake TSA Idaho–Montana border	Reed (1994) Brown et al. (1994)	Minimum and maximum values represent the upper and lower confidence intervals from two different studies.
ICHwk1	1	stand replacement	80	110	Glacier National Park, Canada	Johnson et al. (1990)	Minimum and maximum values represent frequency before and after 1760, respectively; change assumed to result from shift in climatic regime.
IDFdm1	4	stand replacement	41	–	Central Idaho	Barrett (1988)	
		surface/ understorey	7	24	eastern Washington	Agee (1994)	
IDFdm2	4	stand replacement/ crown	40	400	wilderness areas and national forests, western Montana	Arno (1980) Arno et al. (1995)	National forest sample locations consisted of remnant patches of old-growth ponderosa pine.
		underburns/ surface fires	5	85	western Montana	Habeck (1990)	Minimum value represents pre-1850 value. Maximum represents post-1900 attributed to fire suppression.
Msdk	3	stand replacement/ crown fires	50	186	Canadian Rockies Glacier National Park, Montana	Johnson and Larsen (1991) Barrett et al. (1991)	Minimum value for Canadian National Parks pre-1740; post-1740 values were 130–150 years. Post-1928 value of >2700 years unreliable due to limited data points. Maximum for a moist site in Montana.

TABLE 7. (concluded)

Subzone/ variant	NDT	Fire types	Fire frequency Minimum (yr)	Fire frequency Maximum (yr)	Study locations	References	Comments
MSdk	3	variable levels of overstorey mortality	47	–	Idaho–Montana border	Brown et al. (1994)	
		underburns/ surface fires	36	47	Glacier National Parks, Montana	Barrett et al. (1991)	Minimum value is for mesic site west of continental divide, Montana.
					northern Idaho–western Montana	Brown et al. (1995)	

[1] This table include the range of variation for variants assessed in this study. More complete details on additional studies, including other variants in the NFR, are included in Appendix 14.

[2] For sites in Alberta and the northern United States, biogeoclimatic unit was assigned based on tree species composition, understorey species (if available), sited characteristics, and location relative to similar stands in British Columbia.

TABLE 8. A comparison of the assumptions and factors addressed by the Biodiversity Guidebook and this study

Issue	Biodiversity Guidebook[1]	Present study
Theory/models	Negative exponential	Negative exponential, Weibull, others
Multiple distributions considered?	No	No (but examined)
Data for SRIs	Average SRI by variant estimated by the BGB Committee	Inventory data, published studies
Area analyzed	N/A	4.05 million ha in NFR
Harvesting, other biases examined?	No	Yes
Effect of fire suppression examined?	No	Yes
Age variable used to derive seral stage proportions?	SRI (maximum age + regeneration delay)	Average stand age
Is the age variable used contained in operational inventory?	No	Yes
Accuracy of age estimates from inventory	Assumed inaccurate by BGB Committee	Tested with audit plots and found satisfactory for two analytical approaches
SRIs consistent with published material?	High for some variants	Within range for southeast B.C.
Stand age concept used in methodology (relative to tree age)	Not discussed	Unable to consider except theoretically; not contained in present inventory database

[1] The methodology used to derive the natural seral stage proportions of the Biodiversity Guidebook is briefly described in Appendix 4 of that publication. It has not been described in detail either as a formal publication or as a draft.

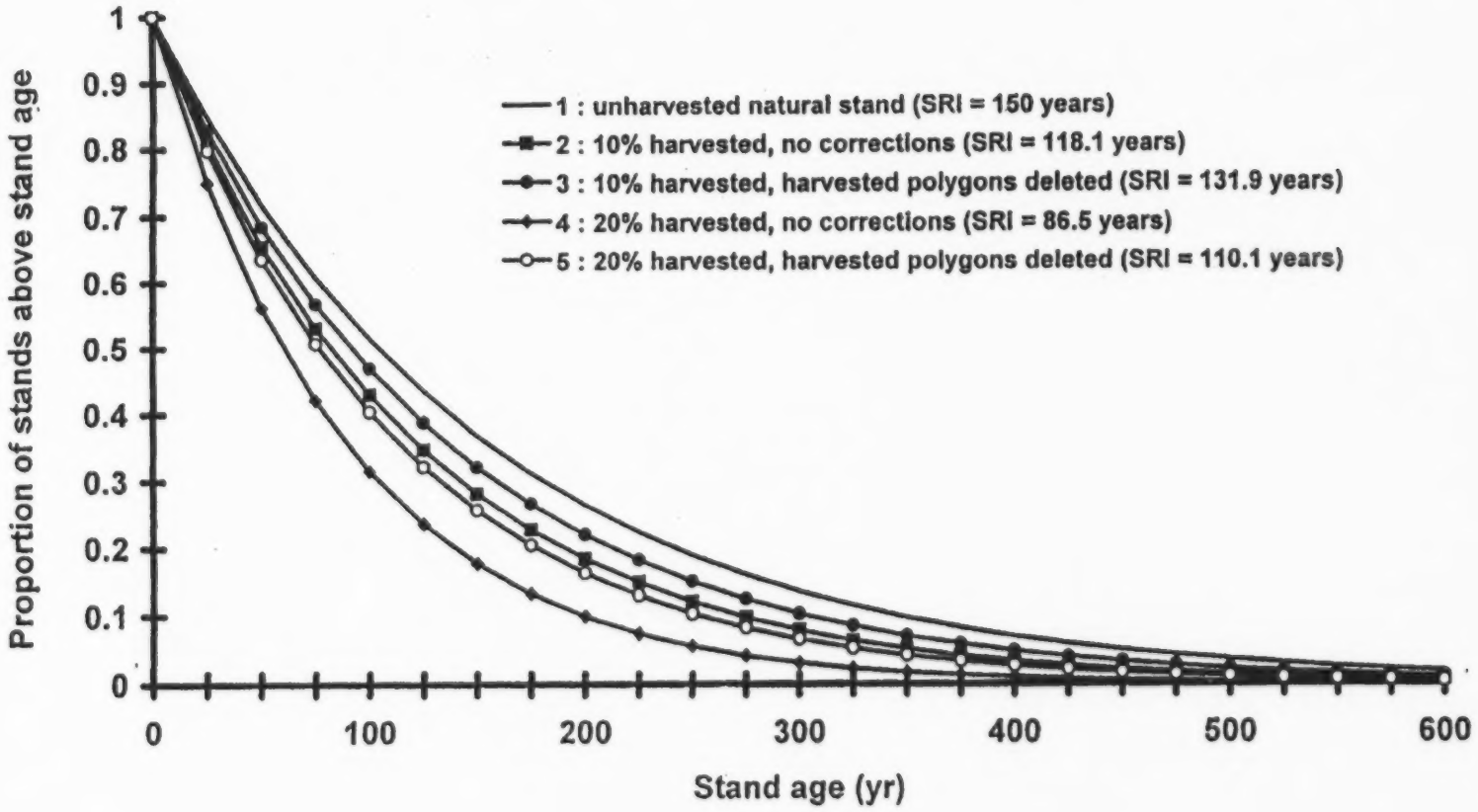

FIGURE 1. Simulated negative exponential age class distributions for a variant with a natural stand replacement interval of 150 years, subjected to 10 and 20% harvest rates.

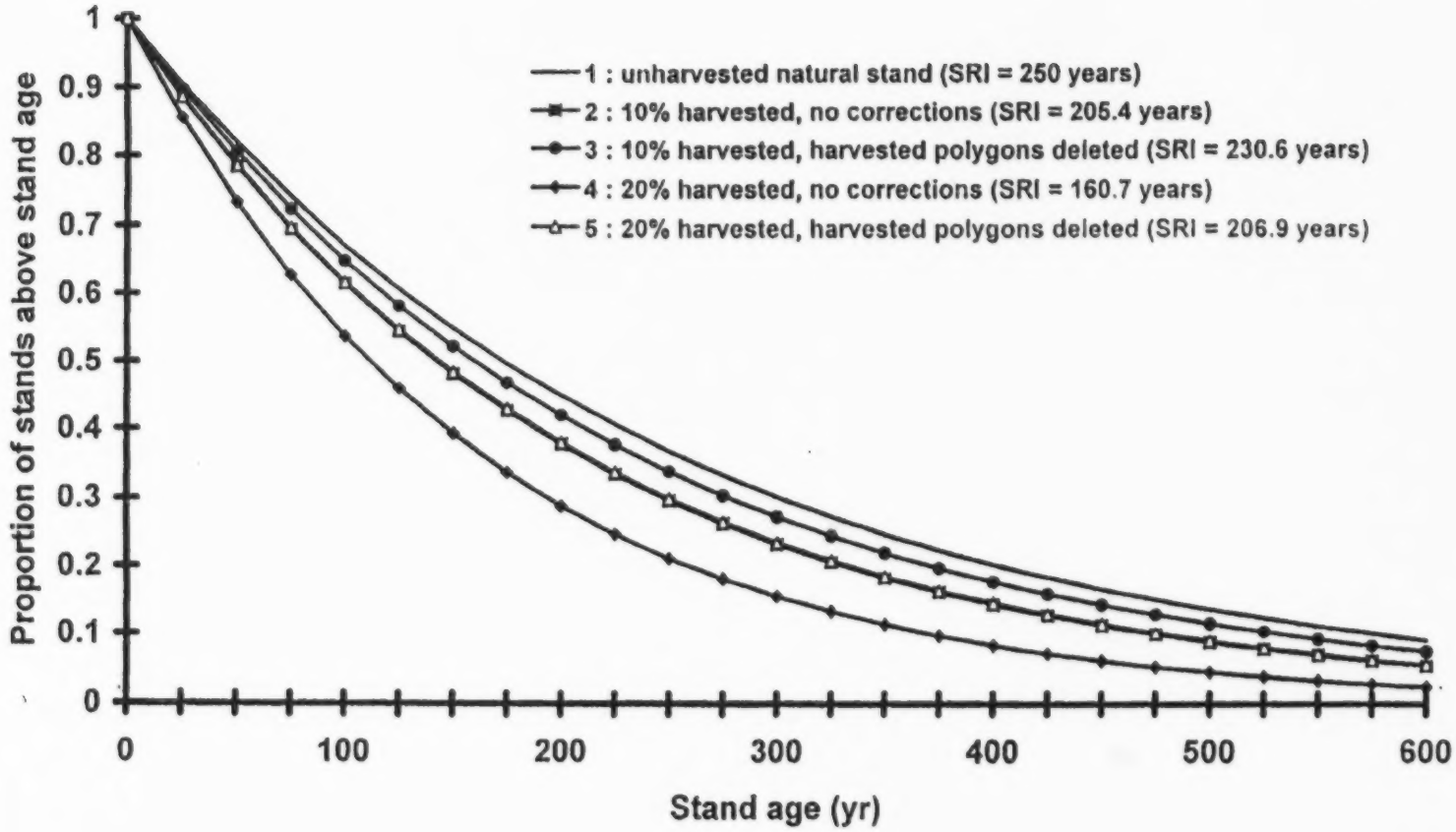

FIGURE 2. Simulated negative exponential age class distributions for a variant with a natural stand replacement interval of 250 years, subjected to 10 and 20% harvest rates. (Note: curves 2 and 5 are almost identical.)

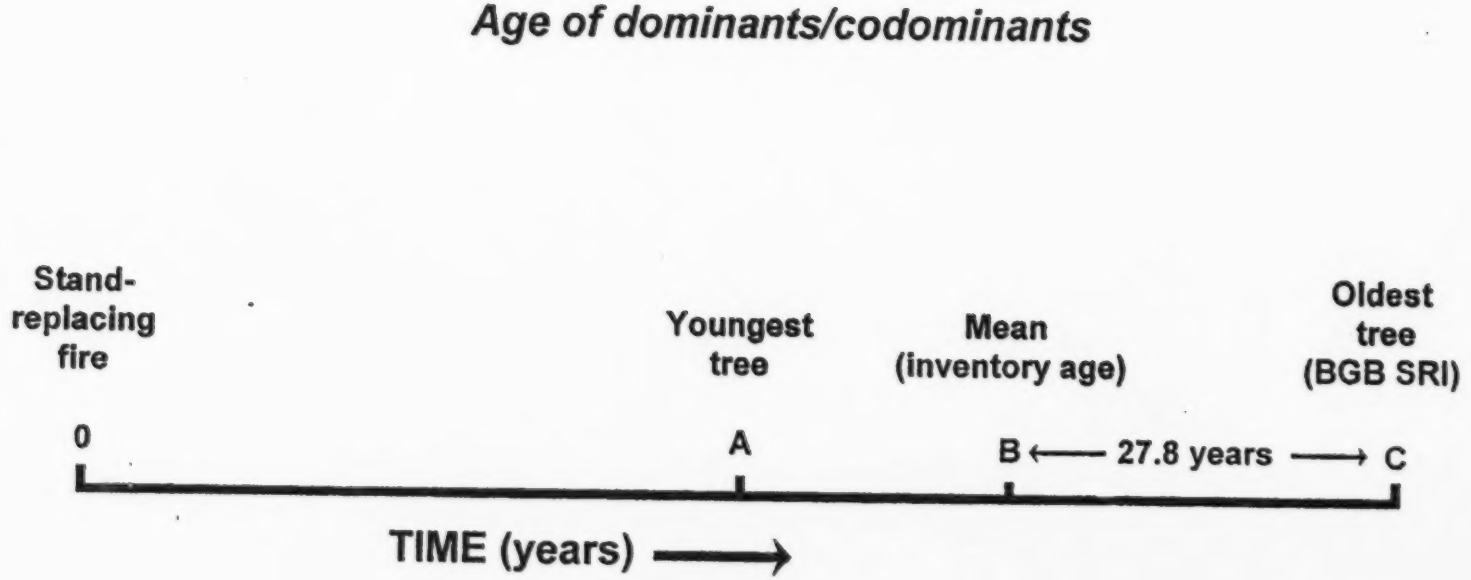

FIGURE 3. Age relationships in a fire-origin stand.

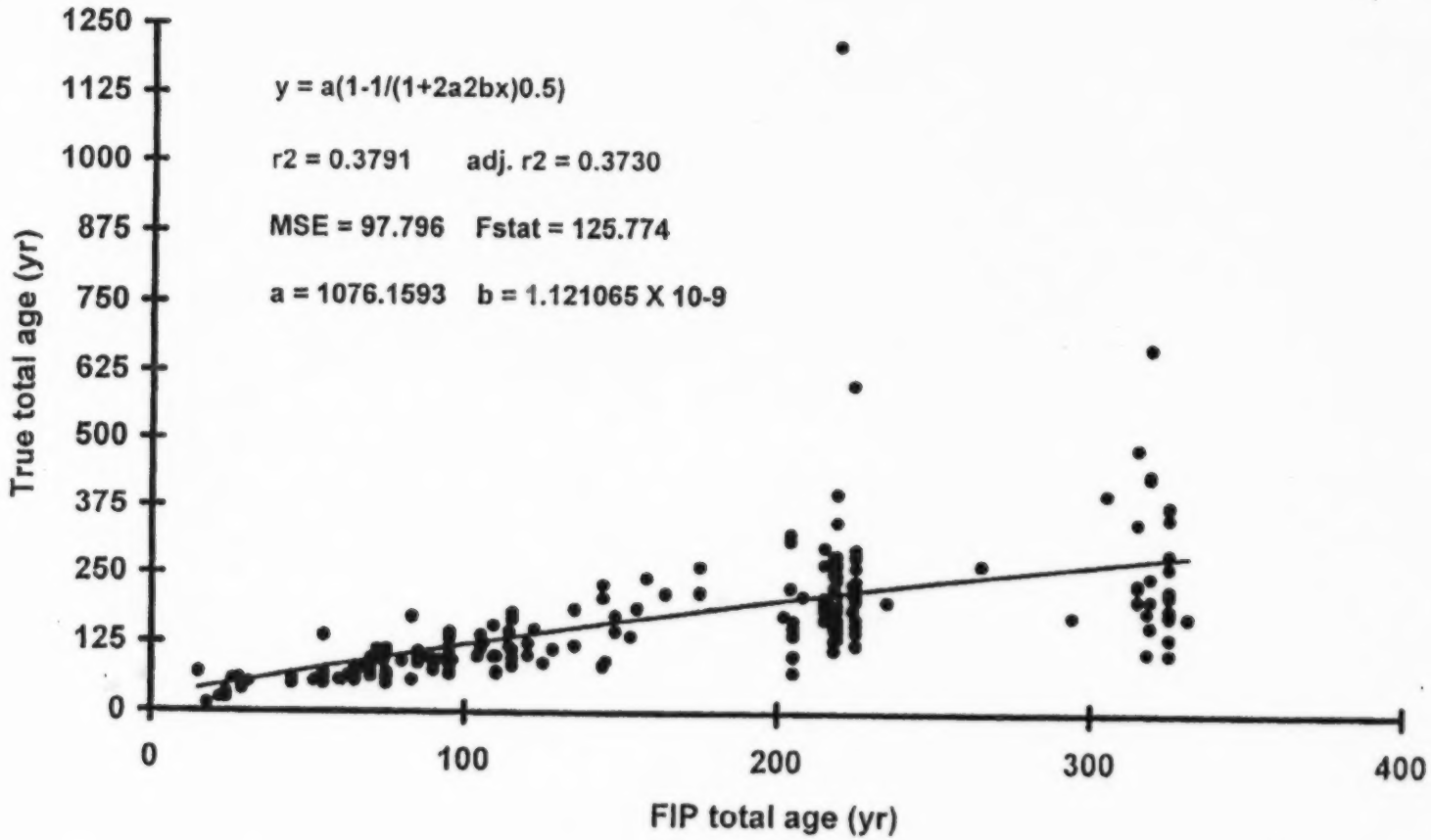

FIGURE 4. Forest inventory age versus audit plot true age based on 208 audit plots in the Nelson Forest Region.

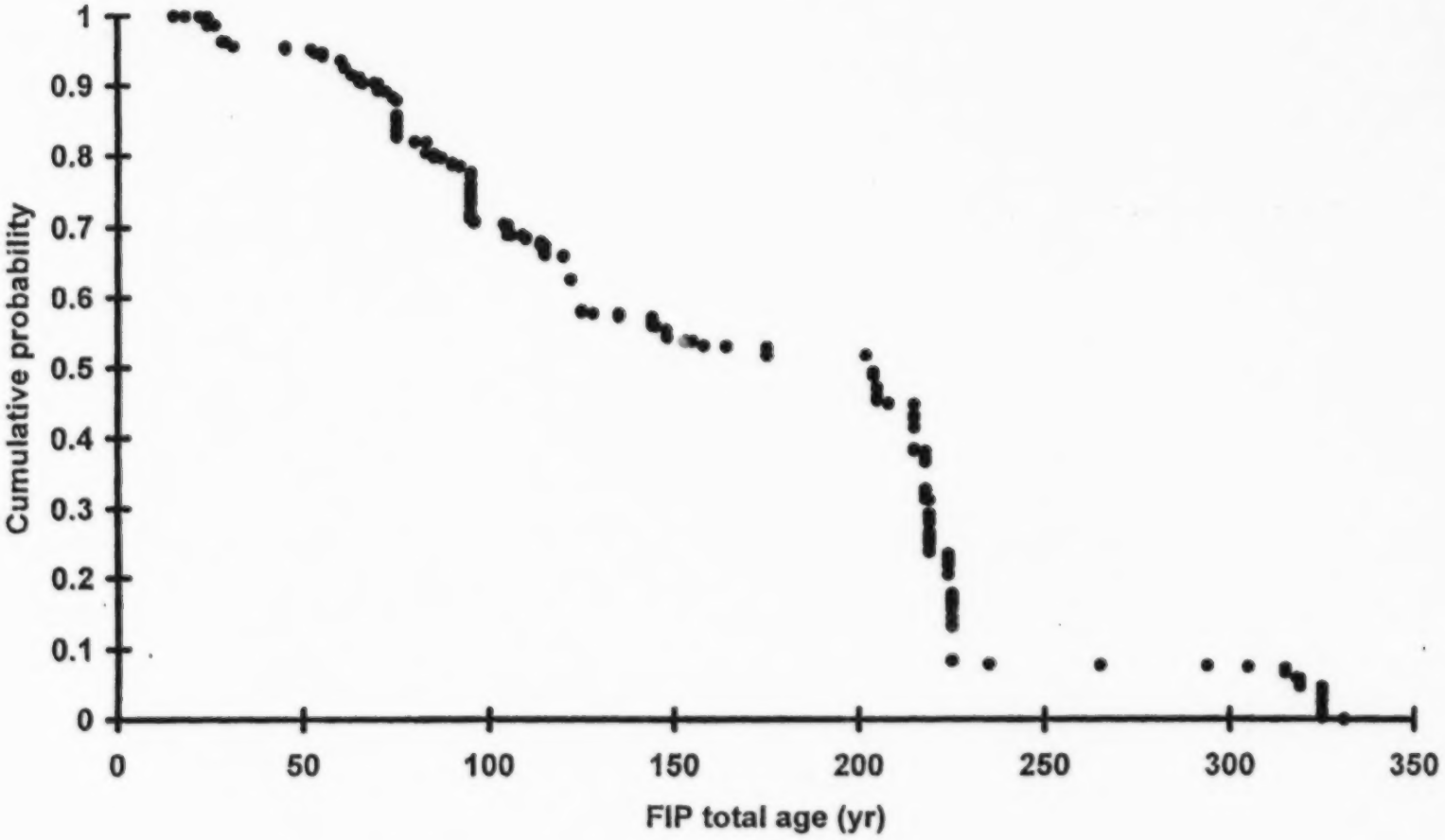

FIGURE 5. Inventory cumulative age class distribution based on 208 audit plots in the Nelson Forest Region.

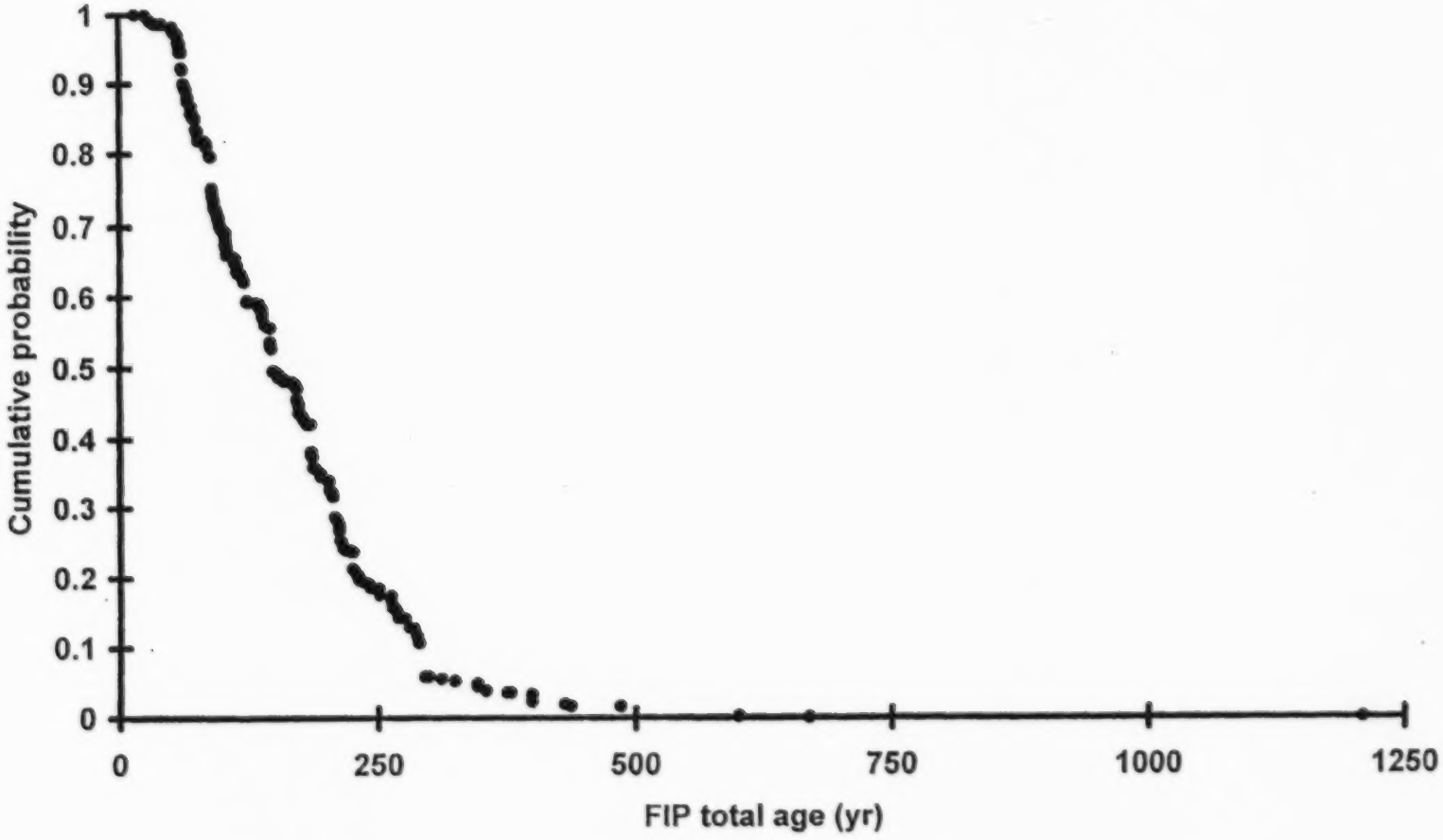

FIGURE 6. Actual cumulative age class distribution based on 208 audit plots in the Nelson Forest Region.

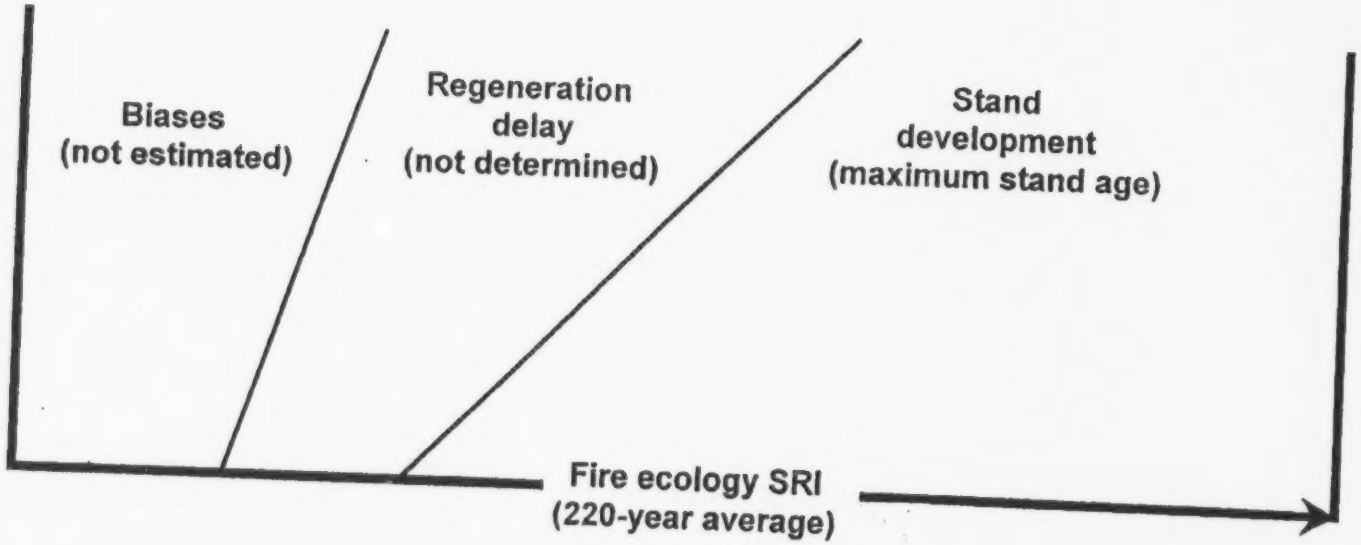

FIGURE 7. Components of a Biodiversity Guidebook stand replacement interval.

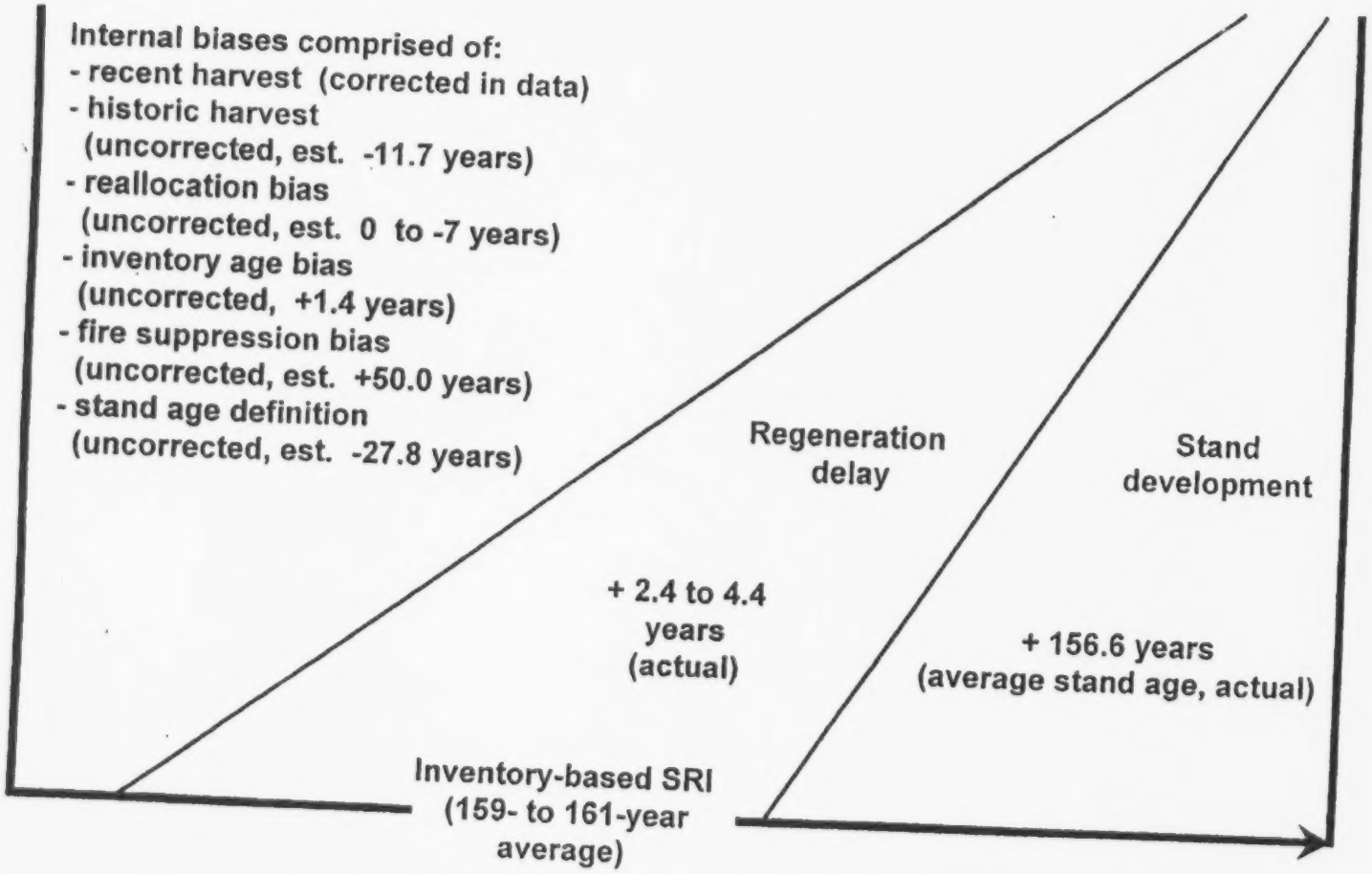
Internal biases comprised of:
- recent harvest (corrected in data)
- historic harvest
(uncorrected, est. -11.7 years)
- reallocation bias
(uncorrected, est. 0 to -7 years)
- inventory age bias
(uncorrected, +1.4 years)
- fire suppression bias
(uncorrected, est. +50.0 years)
- stand age definition
(uncorrected, est. -27.8 years)
Regeneration delay
Stand development
+ 2.4 to 4.4 years (actual)
+ 156.6 years (average stand age, actual)
Inventory-based SRI (159- to 161-year average)

FIGURE 8. Components of an inventory-based stand replacement interval.

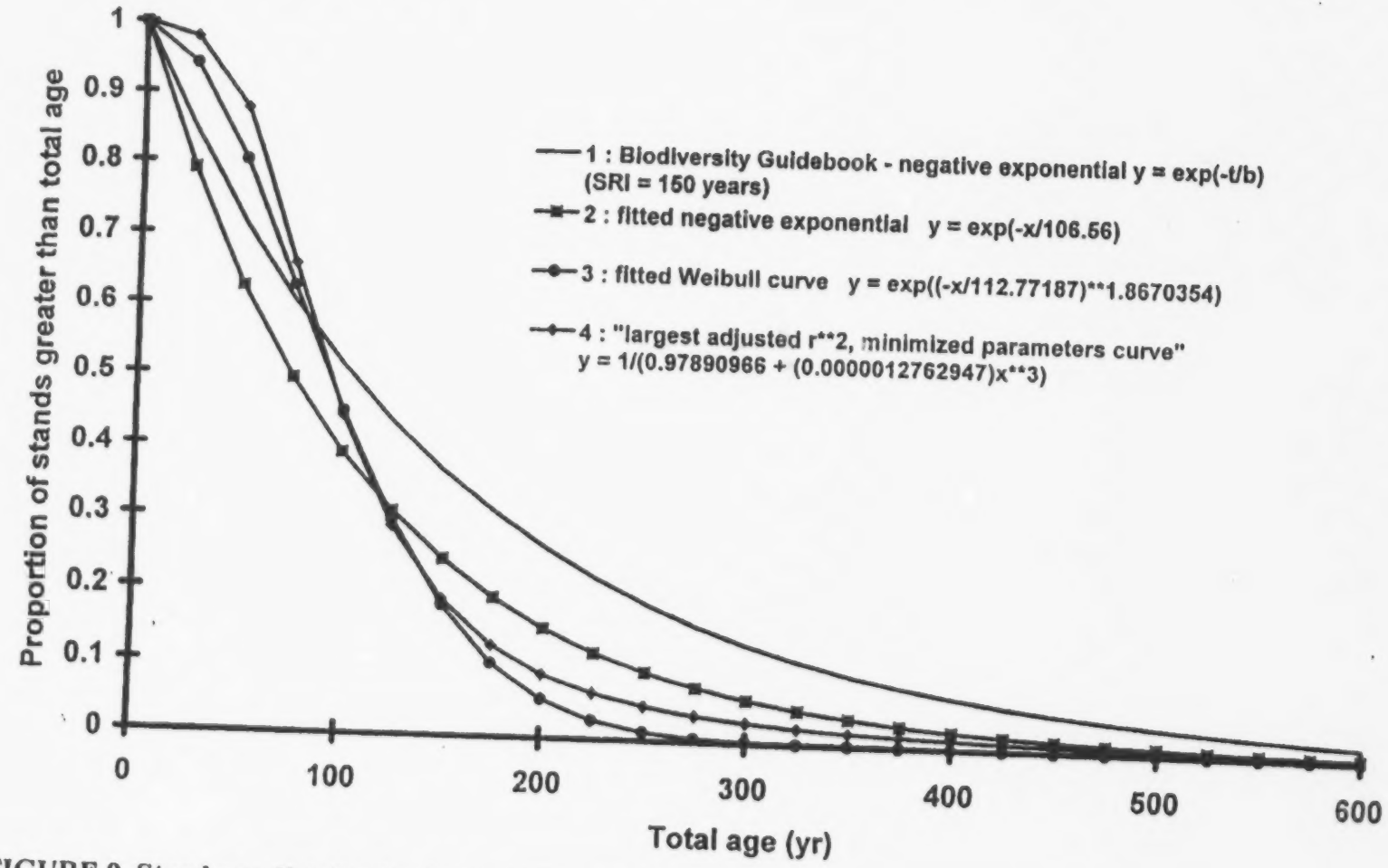

FIGURE 9. Stand age distribution in the MSdm1 derived from negative exponential equation of Biodiversity Guidebook and from other fitted equations.

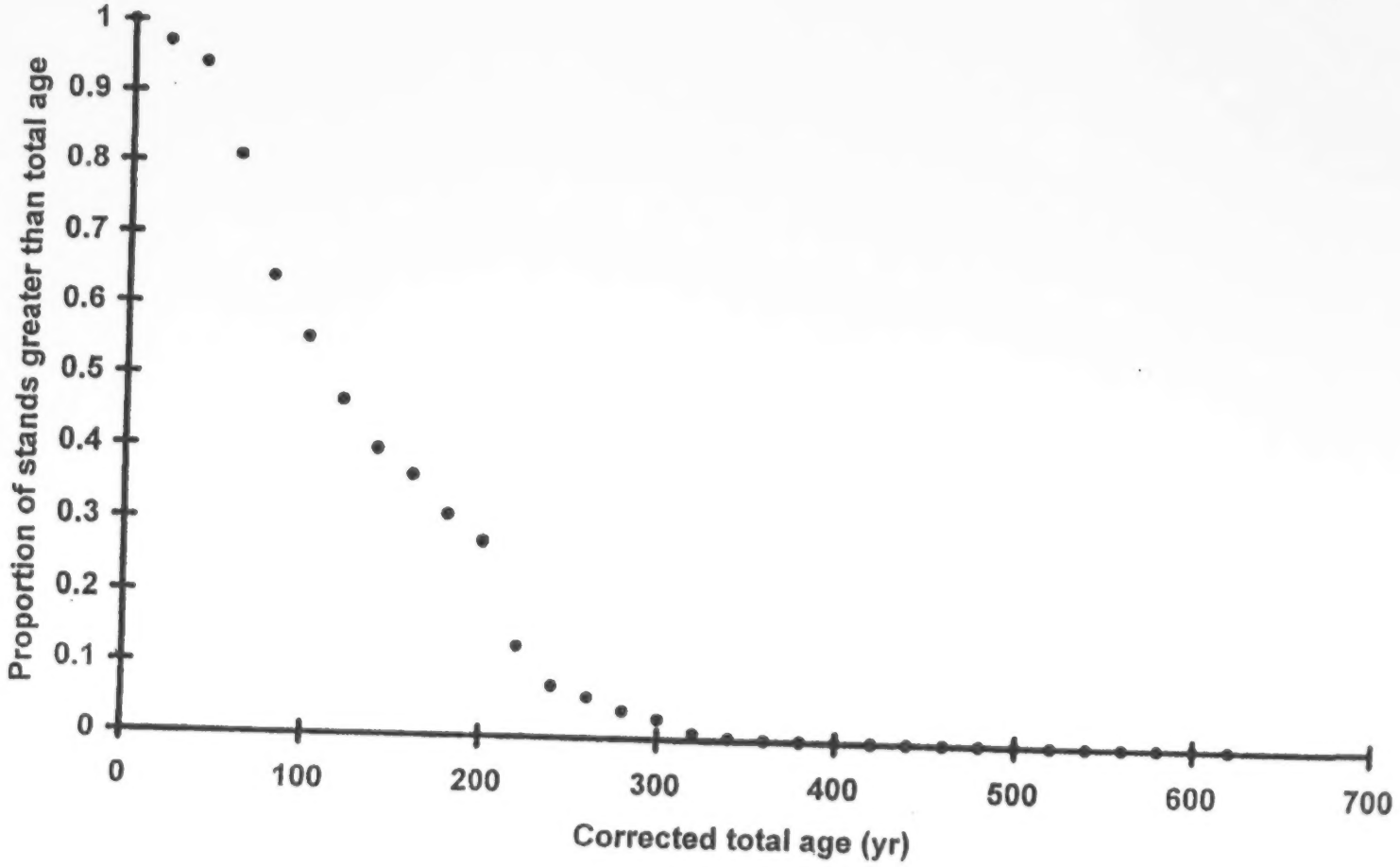

FIGURE 10. Age class distribution in the ESSFdk.

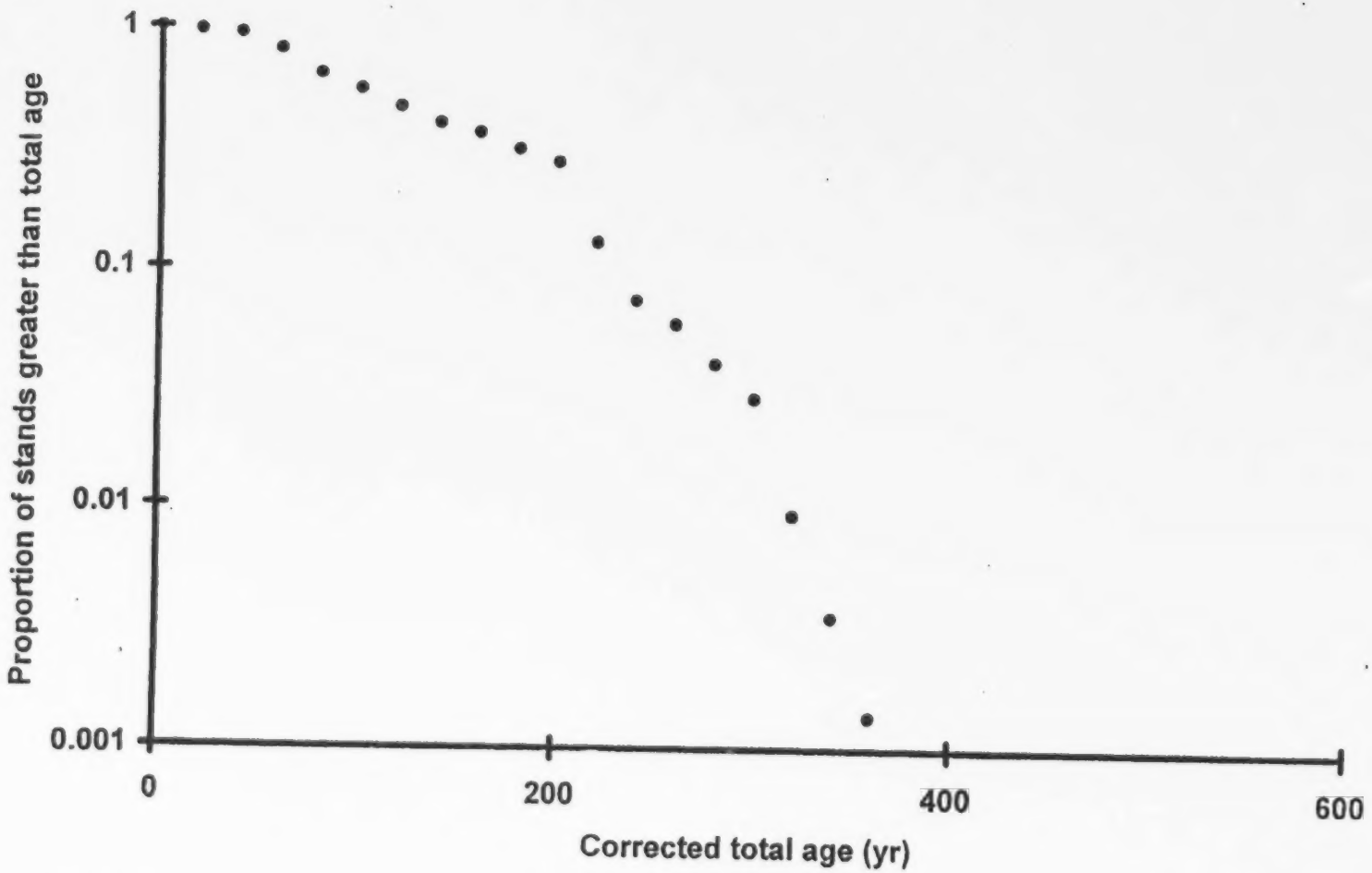

FIGURE 11. Semi-log plot of age class distribution in the ESSFdk.

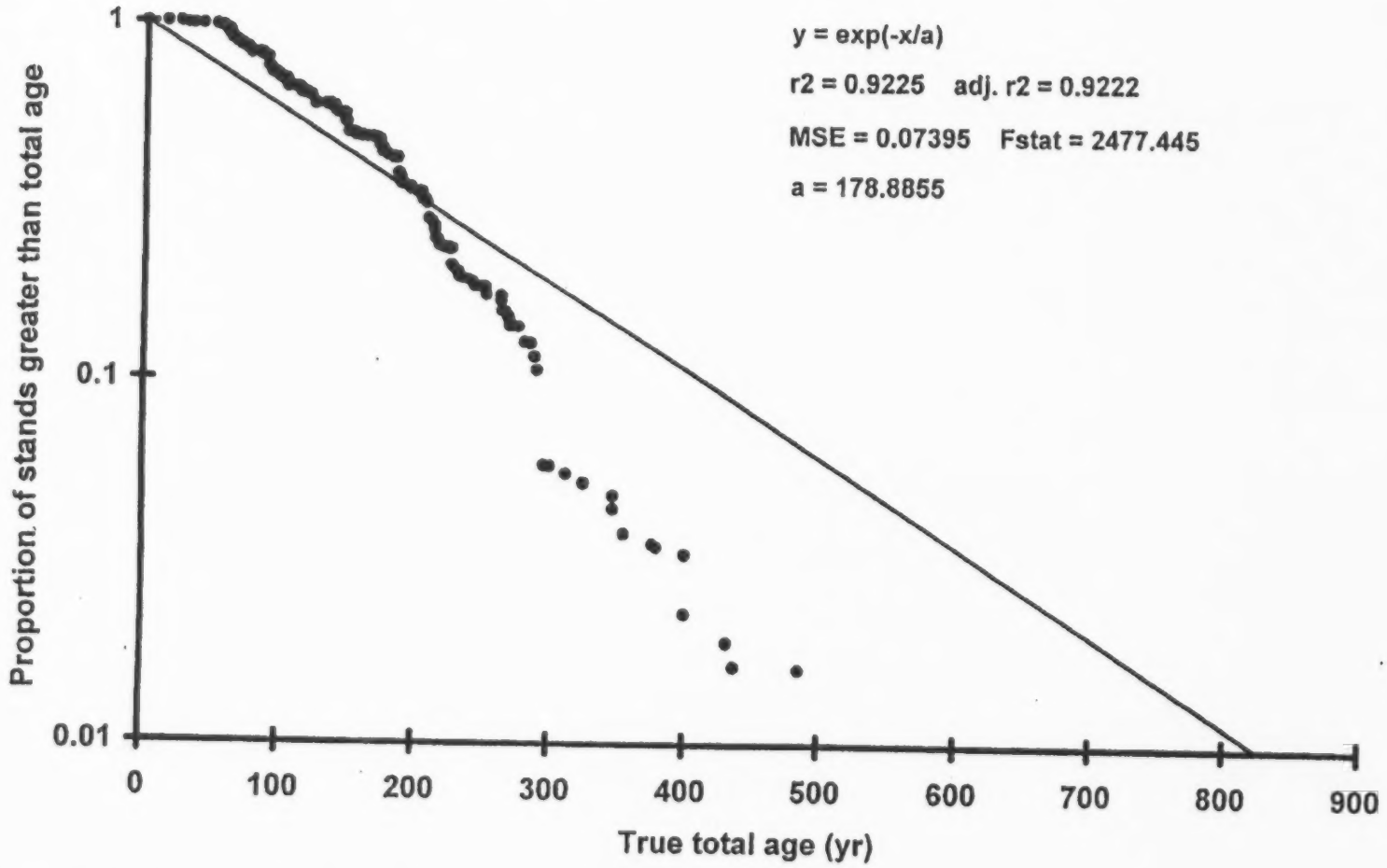

FIGURE 12. Survivorship versus true total age, based on 208 audit plots in the Nelson Forest Region.